STANDARD AMERICAN ELECTRICIAN

A COMPLETE

ENCYCLOPEDIA OF ELECTRICITY

I. A Book of Useful Tables and Practical Hints for Electricians, Foremen, Salesmen, Estimators, Contractors, Architects and Engineers.

II. Practical Diagrams and Descriptions for all Kinds of Electrical Construction Work.

III. Direct and Alternating Current Motors, Showing Principles, Construction, Operation and Maintenance.

IV. Operating and Testing Manual, for Men in Charge of Electrical Apparatus, Repair Men, Trouble Men, Lamp Trimmers and Electricians Generally.

BY

DAVID PENN MORETON
HENRY C. HORSTMANN
VICTOR H. TOUSLEY

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ELECTRICAL TABLES AND DATA

ELECTRICAL TABLES AND ENGINEERING DATA

Acid Fumes.—In places where acid fumes or corrosive vapors may exist, the nature of the vapors will determine the insulation to be used. Consult chemists and Inspection Department having jurisdiction. Conduit work is not favored much in such places, but if it can be shown that the vapors in question are not harmful to the metal it is permissible.

Adapters.—There is no objection to the use of adapters, provided they are of approved type.

Adjusters.—The use of cord adjusters should be discouraged, but there is no very serious objection to the use of any that do not severely damage the cord.

Air Compressors.—Air compressors are usually driven by series wound motors and made to stop and start automatically. For a. c. work induction motors are used. Tanks should be of a capacity equal to about 50 per cent of the rated capacity of the compressor per minute. The air should be dry and cool, as most of the moisture will be precipitated. One H.P. will compress about 5½ cu. ft. of free air per minute to 90 lbs.

Alternating Current Wiring.—For alternating current systems the two or more wires must be run in the same metal conduit, armored cable or metal moulding. In open wiring the greater the separation of wires, the greater will be the inductive drop.

See also special tables for sizes of motor wires and wiring systems.

Alternators.—Alternating current generators and their exciters are not usually provided with fuse protection.

Aluminum.—Aluminum is used as a rule only for outside work and for bus-bars. It can be soldered, but soldering is more difficult than with copper wire and clamps are therefore much used. When used for bus-bars the current density ranges from 1,000 to 1,200 amperes per sq. in. for the smaller sizes, and about 500 for the heavy bars. See *Bus-Bars* for table. For insulated aluminum wire the safe carrying capacity is 84 per cent of that given for copper wire of same insulation. Aluminum is electropositive and must be tied with aluminum wire and no other metal must be allowed to touch it.

Comparison of Copper and Aluminum:

	Aluminum	Copper
Specific gravity	2.68	8.93
Relative specific gravity	1.00	3.33
Conductivity	61 to 63	96 to 99
Weight for equal area	47	100
Area for equal conductivity	160	100
Diameter for equal conductivity	126	100

It will be noted that an aluminum wire of equal conductivity is about two sizes larger by B. & S. gauge than a copper wire. The tensile strength of aluminum is from 20,000 to 35,000 pounds per square inch; that of copper from 20,000 to 65,000. For carrying capacity, etc., see *Wire Calculations*.

Ammeters.—It is customary to provide an ammeter for each generator connected to a switchboard, and only the very smallest and cheapest boards are ever put up without one. The cord sent out with shunt ammeters must always be used full length and need not be protected by fuses. Never place an ammeter

in any lead that can be affected by equalizer current. An ammeter used for battery charging should indicate direction of current.

Ampere's Rule.—Imagine yourself swimming with the current and facing the center of the coil; the left hand will then point toward the north pole of the magnet.

Anode.—The anode is the positive pole.

Annunciators.—Unless the annunciator is known to be especially constructed for high voltage, no attempt should be made to operate it from light or power circuits. Use bell ringing transformers, motor generators or battery. Annunciators cannot be operated in parallel successfully.

Apartment Buildings.—If practicable, meters should be placed in basement. In some cities special rules for the wiring of apartment buildings exist. No cut-outs should ever be placed in closets; place them in kitchen if possible. To determine approximate size of mains necessary to supply lighting in apartment buildings, estimate one watt per square foot and consult table of carrying capacities.

Arcades.—The illumination of arcades should be kept low so as not to interfere with show windows.

Arc Lamps.—In laying out wiring for arc lamps the question of drop need not be considered unless incandescent lamps are also on the circuit. A wire smaller than No. 6 should not be used for theatre, or moving picture arc lamps. Two dissolving stereopticon lamps are usually rated as about equal to one stage or moving picture arc lamp.

Plugs used for arc and incandescent lamps should not be interchangeable. The light from direct current arc lamps is much better than that from alternating current. Series arc lamps are now operated almost entirely from constant current transformers; each transformer being limited to one circuit.

Arc Lamp Data

Type of lamp	Current in amperes	Voltage across arc	Color of light	Point of maximum intensity when used with clear glass globes	Watts per mean spherical candle power	Hours of life of pair of carbons
Open arcs						
Direct current series	6.5—7; 9.6—10	45	Nearly white	45° below the horizontal	1.20—1.30	12—14
Direct current multiple	6—10	45	Nearly white	45° below the horizontal		12—14
Alternating current series	10—15	40	Blue white	Without reflectors 60° above and 60° below the horizontal	1.7—2	8—12
Alternating current multiple	10—15	28	Blue white			8—12
Enclosed arc						
Direct current series	6—6.6	75—80	Bluish white	45° below the horizontal	1.8—2	80—200
Direct current multiple	3—7	75—80	Bluish white	45° below the horizontal	2.60—3.50	80—200
Direct current multiple		140—160	Blue white to violet			80—150
Alternating current series	6—7	75—80	Bluish white	Without reflectors 60° above and 60° below the horizontal	2.40—2.60	80—150
Alternating current multiple	5—6	75—80	Bluish white		2.80—4	80—150
Intensified arc	3.5—5	80	White		1.8—2	80—100
Flaming arc series	6—12		Depends on the carbons used	With inclined carbons directly under lamp. with vertical carbons 20-30° below the horizontal	0.25—0.35	12—200
Flaming arc constant potential current	6—12	35—70			0.30—0.60	12—200
Regenerative flame arc series	5.5—7	70	Yellow	30° below the horizontal	0.30—0.45	60—70
Regenerative flame arc multiple		70	Yellow		0.40—0.60	60—70
Magnetite series	4—6	80	White	10° 20° below the horizontal	1.30—1.50	150—225
Magnetite multiple	4—6	80	White		1.60—1.80	150—225

Armored Cable and Cord.—Armored conductors are very suitable for "fish work." The radius of the curve of the inner edge of any bend must not be less than 1½ inches. Where moisture exists the conductors should be lead-covered under the armor. Armored cable is not nail proof under all circumstances.

TABLE I

Outside Diameters of Armored Cables and Weight Per 100 Ft.
Greenfield Flexible, Steel Armored Conductors

	Solid			Stranded		
	B & S	Dia. in.	Wt. lbs.	B & S	Dia. in.	Wt. lbs.
Single conductors, type D..	14	.378	20	10	.450	23
	12	.384	21½	8	.469	28
	10	.434	26	6	.631	54
	8	.464	28	4	.717	63
	6	.609	54	2	.783	71
				1	.900	98
Twin conductors, BX......	14	.630	45	8	.830	77½
	12	.670	48	6	1.116	121
	10	.720	54	4	1.203	143
Three conductors, BX3....	14	.675	53	8	.890	93
	12	.715	56½	6	1.144	153
	10	.785	66			
Single conductors, DL.....				10	.506	53
				8	.564	72
Lead covered, and steel				6	.713	95
				4	.780	110
armored				2	.825	125
				1	.897	165
Twin conductors, BXL....	14	.730	68	8	.978	136
Steel armored and lead	12	.758	78	6	1.152	205
covered	10	.863	110			
Three conductors, BXL3...	14	.782	78	8	1.056	164
Lead covered and steel	12	.815	97			
armored	10	.933	129			
Steel armored, flexible				18	.414	20
cord, Type E..........				16	.447	22
				14	.625	38
Steel armored, flexible reinforced cord, Type EM.				18	.530	25
				16	.540	26
				14	.652	48

Armory.—Armories are often classed with theatres and assembly halls, and must be wired accordingly. The most important part of an armory is the drill hall. This requires an illumination equal to about two or two and one-half foot candles. This is best obtained by placing large units high up out of the range of vision.

Artists.—Require an adjustable light and pendant drops are most serviceable.

Art Gallery.—Art galleries are also often classed with assembly halls. In illuminating statuary, the aim must be to produce some shadow effect because of the uniformity of color. Lights should be hung high. For white statuary an illumination of two-foot candles will be sufficient; for bronze statuary about four times as much should be provided. Paintings are often illuminated by *strips* and *reflectors*, and also by indirect lighting or Holophane globes. As many paintings must be viewed from a distance, a bright illumination of about five foot candles is recommended.

Asbestos.—This becomes a conductor when wet, and must not be used in damp places. Asbestos less than $\frac{1}{8}$ inch thick is not considered serviceable. Asbestos covered wires are much used for connecting arc lamps and rheostats where the wire is subject to much heat.

Assembly Halls.—The National Electrical Code prescribes that if any part of a building is "regularly or frequently used for dramatic, operatic, moving picture, or other performances or shows, or has a stage used for such performances used with scenery or other stage appliances," it must be classed as a theatre, and wired according to theatre rules. It is usual to specify that all wires must be in conduit and that there must be a separate system of lighting, independent of the main system, for use of

the audience in leaving the building in case of fire, or other emergency.

Attachment Plugs.—Must be of approved type. They should be of the pull-out type, and the socket so placed that the plug can pull out in case strain is put upon it.

Automatic Cut-outs are required to protect every device, or wire, which is connected to any power circuit, except alternators and constant current generators. For details see *Cut-outs.*

Automobiles.—In wiring automobiles it is customary to disregard all ordinary construction rules. Electric motors are connected without any fuse protection. A fuse blowing on a heavy up-grade might cause disaster.

Auto-Starters.—As a general rule, auto-starters are not used with motors smaller than 5 H.P. Auto starters provided with overload release devices, and so arranged that the handle cannot be left in the starting position, are obtainable and should be used. Small auto-starters have usually three taps, and these are arranged to give about 50, 65 or 80 per cent of the line voltage. Larger starters usually have four taps arranged respectively for 40, 58, 70 and 80 per cent of the line voltage. Always make connections to the lowest voltage tap that will give the necessary starting torque. Wherever possible, place starter in sight of motor. For motors smaller than 5 H.P., throw-over switches are often used.

Bakeries.—In bakeries, hot places will be found in which rubber-covered wire is not suitable.

Balance Sets.—Balance sets are made up of motor generators or transformers, and exist for the purpose of obtaining a neutral wire and low voltage for a small lighting load operated in connection with a higher voltage two-wire generator. They are also used where motors operate at two voltages. The

capacity of a balancing set is usually only a small percentage of the total load.

Balancing.—Three-wire systems are usually arranged so that a minimum of current may pass through the neutral wire. A good balance cannot always be obtained, and in some cases considerable judgment is required to determine which is the best arrangement of apparatus. Three wires should be carried to every center supplying more than one circuit. Safety rules require the neutral wire to be of same size as the outside wire, but in large systems this wire will seldom be called upon to carry more than 10 per cent of the current used at any time.

Ball Rooms.—Ball rooms are often classed with theatres. The illumination should be general, and lamps hung high. A general illumination of from two to four foot candles is recommended. Receptacles for musicians' use should be provided.

Banana Cellars.—These places are always hot and moist and the vapors are very corrosive. Conduits corrode very fast, and especially the small screws in outlet boxes; brass screws are often used. Open wiring, if it can be protected, is preferable.

Banks.—In that part of a bank occupied by the clerical force, a general illumination of from three to four foot candles is recommended. These lights are in use most of the time, and high efficiency lamps should be arranged for. In that portion used by the public the illumination is not so much used, and may be of a lower order. Numerous outlets for adding machines and fan motors should be provided. In some banks the private depositors' rooms are fitted with two lights, one above and one below desks, and provided with three-way switches so that only one light can be used at a time; this for convenience of customers who may have dropped things on the floor.

Barber Shops.—Good illumination of barber shops can be arranged for by placing clusters of fairly large candlepower close to the ceiling and a little to the rear of chairs. Placed in this manner, the light will not be forced directly into the line of vision of the customer, and yet give the desired illumination. The mirrors in front of chairs will reflect much of the light back to the chair. Often lights are placed along the mirrors, but this practice is not to be recommended. Outlets for cigar-lighters, curling-iron heaters, vibrators, etc., will be appreciated.

Barns.—The use of brass shell sockets should be avoided in horse barns. Avoid placing lights in front of horses, and keep all lights well up above horses' heads. Use weatherproof construction in wash rooms. Place lights in all dark corners.

Bases.—All electrical contacts must be mounted on non-combustible, non-absorbtive insulating material. Other materials than slate, marble, or porcelain are not favored much, and are allowed only when the first named are too brittle. Sub-bases are generally provided for all switches and other devices which would otherwise allow the wires to come against wood or plaster.

Base Frames.—Base frames are required under all generators and motors, and where the voltage is not in excess of 550 volts it is customary to use insulated base frames. If the motor operates at a voltage in excess of 550, it is better to ground the frame thoroughly. Where frames cannot be insulated they must be grounded.

Basements.—Basements are often damp, and must then be wired in accordance with rules for such places. As ceilings are usually low, protection against mechanical injury is often necessary.

Batteries, Primary.—Dry batteries are much used at the present time. They require no attention and when worn out are simply thrown away. The dry battery is at present made only for open circuit work. The wet battery used mostly for open circuit work consists of carbon and zinc elements immersed in a solution of sal-ammoniac. The carbon is the positive pole. This battery is charged by dissolving about four ounces of sal-ammoniac in sufficient water to fill the jar about three-fourths full. Never use more sal-ammoniac than will readily dissolve. It is preferable to make a saturated solution and, after filtering it through cloth, to add about 10 per cent of water. Keep jars in a cool place to prevent evaporation. Never allow water to freeze. Keep exposed parts covered with paraffine. Do not allow battery to be short circuited or run down. If this has occurred, it will often pick up if left on open circuit for a few hours. If the solution appears milky, more sal-ammoniac is required. Impure zincs which do not eat away evenly facilitate the formation of crystals which greatly increase the resistance. The best known of the closed circuit batteries is the gravity type. The elements in this cell are zinc and copper, immersed in a solution of sulphate of copper (blue vitriol). The copper element rests on the bottom of the jar, and the blue vitriol is placed around it and the jar filled with clean water. The cell must be short circuited for a few hours to start the action. The blue solution should rise to about midway between the two elements. This cell must be kept in action or it will rapidly deteriorate.

Connect all batteries so that the resistance of the battery is nearest equal to the resistance of the devices it is to operate. Series connection should be used when the external resistance is higher than the internal battery resistance. If the external resist-

ance is lower than that of the battery, group cells in multiple. When arranging small storage batteries to be charged from lighting or power circuits, provide double throw switches to entirely disconnect battery from power circuit while it is on the bell circuit. Install all wiring subject to power voltage in accordance with rules for that voltage.

Batteries, Secondary.—Small storage batteries may be carried about and used. The larger ones must remain stationary and are used as compensators for feeder drop, equalizers on three-wire systems, preventives against shut down and as a combination of all of these. Medium size storage batteries are also much used with automobiles. All storage batteries with exception of the Edison, use lead plates. The active material is sponge lead immersed in a weak solution of sulphuric acid. The positive plates when fully charged are of a chocolate color and the active material is quite solid. The negative plate is more of a slate color and softer. The unit of capacity is the ampere hour. A 60-ampere-hour battery, for instance, can deliver a current of three amperes for twenty hours, or seven and one-half amperes for eight hours. High voltages are obtained by connecting a number of cells in series. High amperage is obtained by connecting plates in parallel. The voltage is independent of the size of the cell, but the amperage capacity varies with the surface of the opposed plates. The efficiency is roughly about 75 per cent. The safe rate of charge and discharge varies from five to ten amperes per square foot of positive plate surface, both sides of plate being measured. The voltage should never be allowed to fall below 1.8, and when fully charged is about 2.6. The condition of full charge is indicated by both the positive and negative plates gassing freely.

Before manipulating or attempting to connect any storage battery, the instructions of the maker should be obtained. The following instructions form only a general guide: Keep electrolyte well above plates. See that the cells are kept clean and allow nothing that could short-circuit the plates to accumulate at the bottom. Keep whatever separators there may be in place. Allow no metal except lead in the battery room. Insulate cells from ground and from each other. See that battery is recharged as soon as possible after being used. Do not overcharge. When the negative plates begin to give off gas, it is time to quit. Never allow the voltage to fall below 1.75 per cell. The temperature of the battery should not rise above 110 degrees. The capacity of battery needed is governed by number of units in the generating plant. It is not likely that more than one unit will give out at a time.

Bells.—Bell-ringing transformers are much used in connection with alternating current in place of batteries. To operate bells in series, jump circuit breaker on all but one. If bells are to be operated from lighting circuits, the wiring must be installed in accordance with rules for the voltage used, and the bell must be specially approved for that service. The chief hazard that exists with low voltage bell wires is the possibility of coming in contact with other wires. If storage batteries of high amperage capacity are used, the wires should have fuse protection.

Belting.—Figure 1 is an illustration of a serviceable method of belt lacing. Thread lacing from left to right according to heavy lines, double up at ends and return to starting point; cross lacing on outside of belt only, and keep laces on inside parallel with length of belt.

Holes should be punched as nearly as possible according to the following table:

TABLE II

Width of Belt

Distance from edge of belt—	2 to 6 in.	6 to 12 in.	12 to 18 in.	18 to 24 in.
First row	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	1
First row	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	1
Second row	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{3}{8}$
Second row	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2
Distance apart of each row of holes	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2
Size of lace leather	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$

If pulleys are of same size, or far apart if of different sizes, the length of belt can be quite approximately found by the following rule: Add diameters

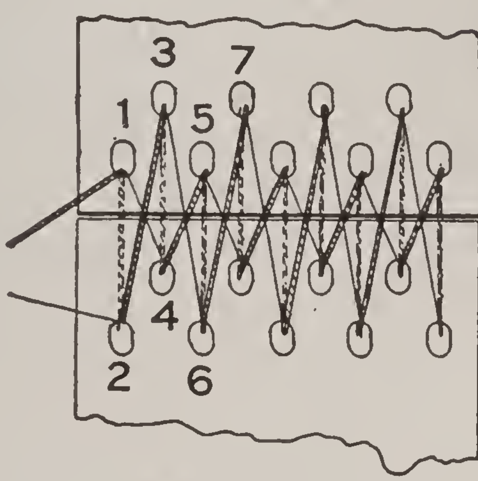


Figure 1.—Method of Belt Lacing.

of pulleys and multiply by 1.57; to this add 2 times the center-to-center distance. The length of belting contained in a roll can be found by reference to Table III. Multiply number of layers in roll by number found where outside diameter of roll and diameter of hole in center cross.

Example.—A roll of belting of 48 inches outside diameter has a hole in the center six inches in diam-

eter, and there are 88 layers of belting. Where the line pertaining to 48 inches outside diameter crosses the line pertaining to 6-inch hole, we find the number 7.04, which multiplied by 88 gives 619.52 feet of belting. The width of a single belt necessary to perform a certain amount of work can be found by the formula $W = 1200 \times \text{H.P.} \div V$, where W stands for width, H.P. for horsepower, and V for velocity of belt in feet per minute. This formula will give a belt of ample size, and a smaller one can be made to do the work by giving it greater tension. Table IV is calculated from the above formula and shows the capacity of belts of various widths and operating at various velocities.

Belts should run horizontally and the pull should be on the under side. Tightener should be on slack side and close to main pulley. Belts running vertically must be kept very tight, especially if the lower pulley is small. The proportion between two pulleys close together should not be greater than 6 to 1. Double belting should not be used on pulleys less than 3 feet in diameter. Rubber belting is preferable in damp places. Thin belting is best for high speeds. Belts operating at high speeds should be cemented, not laced. Pulleys should be perfectly smooth.

Billboards.—A very bright illumination of from ten to twenty foot candles is often used. Lights must be encased in reflectors so as not to be visible to the observer. Install wiring according to rules for outside work.

Billiard Halls.—A general illumination of about one foot candle is recommended. Above each table there should be an illumination of four or five-foot candles. The light over the table should be uniform. At least two lamps should be provided for each table, and should be so encased that the lights are

TABLE III

Table for Calculating Length of Belting, Rope or Wire in Coils

Outside Diameter	Diameter of Hole in Inches 2	3	4	5	6	7	8	9	10	11	12
6 in.	1.05	1.17	1.30	1.44							
7 in.	1.17	1.31	1.44	1.57	1.70						
8 in.	1.31	1.44	1.57	1.70	1.83	1.96					
9 in.	1.44	1.57	1.70	1.83	1.96	2.09	2.23				
10 in.	1.57	1.70	1.83	1.96	2.09	2.23	2.46	2.49			
11 in.	1.70	1.83	1.96	2.09	2.23	2.36	2.49	2.62	2.75		
12 in.	1.83	1.96	2.09	2.23	2.36	2.49	2.62	2.75	2.88	3.01	
13 in.	1.96	2.09	2.23	2.36	2.49	2.62	2.75	2.88	3.01	3.14	3.27
14 in.	2.09	2.23	2.36	2.49	2.62	2.75	2.88	3.01	3.14	3.27	3.40
15 in.	2.23	2.36	2.49	2.62	2.75	2.88	3.01	3.14	3.27	3.40	3.53
16 in.	2.36	2.49	2.62	2.75	2.88	3.01	3.14	3.27	3.40	3.53	3.66
17 in.	2.49	2.62	2.75	2.88	3.01	3.14	3.27	3.40	3.53	3.66	3.79
18 in.	2.62	2.75	2.88	3.01	3.14	3.27	3.40	3.53	3.66	3.79	3.92
19 in.	2.75	2.88	3.01	3.14	3.27	3.40	3.53	3.66	3.79	3.92	4.06
20 in.	2.88	3.01	3.14	3.27	3.40	3.53	3.66	3.79	3.93	4.06	4.19
22 in.	3.14	3.27	3.40	3.53	3.66	3.79	3.92	4.05	4.19	4.32	4.45
24 in.	3.40	3.53	3.66	3.79	3.92	4.05	4.19	4.31	4.45	4.58	4.72
26 in.	3.66	3.79	3.92	4.05	4.18	4.31	4.45	4.57	4.71	4.84	4.97
28 in.	3.92	4.05	4.18	4.31	4.44	4.57	4.71	4.83	4.98	5.11	5.24
30 in.	4.18	4.31	4.44	4.57	4.70	4.83	4.98	5.09	5.23	5.36	5.50
32 in.	4.44	4.57	4.70	4.83	4.96	5.09	5.24	5.35	5.49	5.62	5.75
34 in.	4.70	4.83	4.96	5.09	5.22	5.35	5.50	5.62	5.75	5.88	6.01
36 in.	4.96	5.09	5.22	5.35	5.48	5.67	5.76	5.88	6.02	6.15	6.28
38 in.	5.22	5.35	5.48	5.61	5.74	5.88	6.02	6.14	6.28	6.41	6.54
40 in.	5.48	5.61	5.74	5.87	6.00	6.14	6.28	6.41	6.57	6.68	6.82
42 in.	5.74	5.87	6.00	6.13	6.26	6.40	6.54	6.67	6.81	6.94	7.08
44 in.	6.00	6.13	6.26	6.39	6.52	6.66	6.80	6.93	7.07	7.20	7.34
46 in.	6.26	6.39	6.52	6.65	6.78	6.92	7.06	7.19	7.33	7.46	7.60
48 in.	6.52	6.65	6.78	6.91	7.04	7.18	7.32	7.45	7.56	7.72	7.86

This table may also be used to estimate length of rope or wires in coils if number of turns can be determined.

TABLE IV

The table below is calculated from the above formula and shows the number of H. P. belts will transmit

Belt Speed in Ft. Per Min.	Width of Belt in Inches 1	2	3	4	5	6	7	8	9	10
200	.16	.33	.50	.66	.83	1.00	1.16	1.33	1.50	1.66
300	.25	.50	.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
400	.33	.66	1.00	1.32	1.66	2.00	2.33	2.66	3.00	3.32
500	.42	.84	1.25	1.67	2.10	2.50	2.95	3.34	3.75	4.20
600	.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00
700	.58	1.14	1.75	2.33	2.90	3.42	4.08	4.67	5.25	5.80
800	.67	1.34	2.01	2.66	3.34	4.02	4.67	5.33	6.00	6.68
900	.75	1.50	2.25	3.00	3.75	4.50	5.25	6.00	6.75	7.50
1000	.83	1.66	2.49	3.33	4.15	4.98	5.83	6.66	7.50	8.30
1200	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.0
1400	1.16	2.32	3.50	4.67	5.80	7.00	8.13	9.34	10.5	11.6
1600	1.33	2.66	4.00	5.33	6.66	8.00	9.33	10.6	12.0	13.3
1800	1.50	3.00	4.50	6.00	7.50	9.00	10.5	12.0	13.5	15.0
2000	1.67	3.34	5.00	6.67	8.36	10.0	11.7	13.4	15.0	16.7
2200	1.83	3.66	5.50	7.32	9.15	11.0	12.8	14.6	16.5	18.3
2400	2.00	4.00	6.00	8.00	10.0	12.0	14.0	16.0	18.0	20.0
2600	2.16	4.32	6.50	8.66	10.8	13.0	15.1	17.3	19.5	21.6
2800	2.33	4.66	7.00	9.33	11.6	14.0	16.3	18.6	21.0	23.2
3000	2.50	5.00	7.50	10.0	12.5	15.0	17.5	20.0	22.5	25.0
3200	2.66	5.32	8.00	10.6	13.3	16.0	18.6	21.2	24.0	26.7
3400	2.83	5.66	8.50	11.3	14.1	17.0	19.8	22.6	25.5	28.2
3600	3.00	6.00	9.00	12.0	15.0	18.0	21.0	24.0	27.0	30.0
3800	3.16	6.32	9.50	12.6	15.8	19.0	22.1	25.2	28.5	31.6
4000	3.33	6.66	10.0	13.3	16.6	20.0	23.3	26.6	30.0	33.2
4200	3.50	7.00	10.5	14.0	17.5	21.0	24.5	28.0	31.5	35.0
4400	3.67	7.34	11.0	14.6	18.3	22.0	25.6	29.2	33.0	36.6
4600	3.83	7.66	11.5	15.3	19.1	23.0	26.8	30.6	34.5	38.2
4800	4.00	8.00	12.0	16.0	20.0	24.0	28.0	32.0	36.0	40.0
5000	4.17	8.34	12.5	16.7	20.9	25.0	29.2	33.4	37.5	41.8

TABLE V

Table showing approximate lengths of material which must be cut out of belts to double the tension; sag on upper and lower sides assumed equal. Reducing sag by one-half approximately doubles the tension.

Distance Between Pulley Centers in Feet	Dimensions Below in 64th of an Inch								
4—Sag	31	46	62	77	92	108	123	138	154
Cutout	..	2	3	5	7	10	13	17	20
6—Sag	46	69	92	115	138	161	184	207	231
Cutout	1	3	5	7	11	15	19	25	30
8—Sag	62	92	123	154	185	216	246	277	308
Cutout	1	4	6	10	15	20	26	33	41
10—Sag	77	115	154	192	230	269	307	346	384
Cutout	1	4	8	12	18	25	32	41	50
12—Sag	92	138	184	230	276	322	368	415	462
Cutout	2	5	9	14	21	29	38	49	59
15—Sag	115	173	231	288	345	402	459	518	577
Cutout	2	7	12	18	28	37	48	62	76
18—Sag	138	207	277	346	415	485	554	623	693
Cutout	3	8	14	22	33	44	58	74	91
21—Sag	161	242	323	404	485	566	647	727	807
Cutout	3	9	16	26	39	51	70	87	106
25—Sag	192	288	384	480	576	672	768	864	960
Cutout	4	12	19	31	46	61	81	104	127
30—Sag	231	346	461	576	691	806	921	1036	1151
Cutout	4	14	23	37	55	74	97	124	152

The above table is based upon the ratio of deflection and elongation of wires in spans, and it is assumed that the additional strain produces no immediate elongation of the belt.

not visible to the players. A switch for each table will be a convenience. Outlets for cigar-lighters and fan motors should be provided.

Bonds.—Rail bonds should not be smaller than No. 000. The area of contact should be about eight times the cross section of the bond. In some instances the size of bond is determined by the size of supply wires, the total cross section of all bonds at any point being made equal to the cross section of the supply wires for that point. For a ratio of 1:12 the copper in circular mils necessary to equal the conductivity of steel rails can be found by multiplying the weight per yard of rail by 10,000.

Boosters.—Boosters may be in the form of transformers or motor generators, and are used to raise or lower voltage, also in some cases in return railway circuits to lessen electrolysis. The installation of boosters is not profitable except on long lines when the cost of copper to prevent the drop is greater than the cost of boosters. Boosters may be compounded so that the regulation becomes automatic.

Bowling Alleys.—The illumination should be arranged so that no light is visible to the players. An illumination equal to one and one-half or two foot candles is advisable for the alley, and about double that much for the pins.

Branch Blocks must always provide double pole fuse protection for each circuit.

Branch Circuits.—The term, "branch circuit," is here used to describe that part of the wiring between the last fuse and the lights, motors, heaters, or other translating devices. Branch circuits should be grouped as far as possible and arranged so that the cut-out cabinet may be in a safe and convenient place. It is advisable to place the switches outside of cut-out cabinets. In the best arranged theatres

all branch circuits, except those for emergency lights, are carried to stage switchboards. By running mains as far as possible, and shortening the branch circuits, a much evener voltage at lamps will be secured than is possible from long branch circuits. The drop in voltage should never be over 2 per cent. Most lamps are marked for three voltages, top, middle, and bottom, and there is a difference of four volts between them. With a 4 per cent drop a 110-volt lamp will be at different times subject to all three voltages and the illumination will vary greatly.

For best location of cut-outs, see table on calculation of materials. The following table shows drop in voltage with different wires at different distances. A run of No. 14 wire 110 feet long feeding twelve lights evenly spaced ten feet apart will cause a drop of about one and one-quarter volts between first and last lamps. The table below shows the drop with wires from No. 14 to 6, carrying six amperes the distances given at top of table.

TABLE VI

Distance in feet; one leg

B & S	20	40	60	80	100	120	140	160	180	200
14 ..	.63	1.3	1.9	2.5	3.2	3.8	4.4	5.0	5.7	6.3
12 ..	.40	.80	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0
10 ..	.25	.50	.75	1.0	1.3	1.5	1.8	2.0	2.3	2.5
8 ..	.15	.30	.45	.60	.75	.90	1.1	1.2	1.4	1.5
6 ..	.10	.20	.30	.40	.50	.60	.70	.80	.90	1.0

Burglar Alarm.—A good burglar alarm is one so wired that it is under constant test, so as to give immediate notice when any part of it is out of order. The closed circuit system complies with this requirement. With open circuit systems it is best to provide "silent test" by which it can be tried out every night without causing an alarm. To guard against purposive incapacitating, some installations **are**

mixed open and closed circuit system, so that it is impossible to know which wire to cut or short-circuit in order to prevent an alarm. In some systems "balanced" relays are used and the wires are interwoven so that it is impossible to interfere with them in any way without giving an alarm. Where either the simple open or closed circuit system is used, the wires and batteries should be protected against interference.

Bus-Bars.—The term, "bus-bar," refers, strictly speaking, only to those conductors on a switchboard which are connected directly to all of the machines. In common practice, however, it is understood that all of the current-carrying bars on a switchboard come under this classification. For high voltages it is usual to cover the bars with insulation, but for low voltages it is customary to leave them bare. The proper separation of bus-bars is 2½ inches for voltages less than 300, and 4 inches for the higher, including 550 volts. Copper and aluminum are used. Systematize bus-bars by placing all positive poles at top or right-hand side of circuit. A current density of 1000 amperes per square inch is common practice for bus-bars, but is too high for the large ones.

Table number VII shows the current-carrying capacity of bus-bars calculated on a basis of 1000 amperes per square inch cross section. For very small bars 1½ times as much current may be allowed, while for the very large ones not more than half the current given in the table should be used. The carrying capacity of aluminum is given as 84 per cent of that of copper.

Bushings.—In connection with very high voltages, specially constructed bushings must be used through walls. Ordinary bushings cause trouble. If possible the wires should be run in without touching anything.

TABLE VII

Table of Bus-Bar Data

Thickness	Width	Area in Sq. in.	Lbs. Per Foot Copper	Lbs. Per Foot Aluminum	Carrying Capacity 1000 Amp. Per Sq. In. Copper	Carrying Capacity 840 Amperes Per Sq. In. Aluminum
1/16	1/2	.0313	.1205	.0361	32	27
1/16	3/4	.0469	.1807	.0542	47	39
1/16	1	.0625	.2410	.0723	63	53
1/16	1 1/2	.0938	.3615	.1084	95	80
1/8	1/2	.0625	.2410	.0723	63	53
1/8	3/4	.0938	.3615	1084	95	80
1/8	1	.1250	.4820	.1446	125	105
1/8	1 1/2	.1875	.7230	.2169	188	158
1/8	2	.2500	.9640	.2892	250	210
1/4	3/4	.1875	.7230	.2169	188	158
1/4	1	.2500	.9640	.2892	250	210
1/4	1 1/4	.3125	1.205	.3615	315	265
1/4	1 1/2	.3750	1.446	.4338	375	315
1/4	1 3/4	.4375	1.687	.5061	435	365
1/4	2	.5000	1.928	.5784	500	420
1/4	2 1/4	.5625	2.169	.6507	565	475
1/4	2 1/2	.6250	2.410	.7230	625	530
1/2	3/4	.3750	1.446	.4338	375	310
1/2	1	.5000	1.928	.5784	500	420
1/2	1 1/4	.6250	2.410	.7230	625	525
1/2	1 1/2	.7500	2.892	.8676	750	630
1/2	1 3/4	.8750	3.374	1.1122	875	735
1/2	2	1.000	3.856	1.1568	1000	840
1/2	2 1/4	1.125	4.338	1.3014	1125	995
1/2	2 1/2	1.250	4.820	1.4460	1250	1050
1/2	2 3/4	1.375	5.304	1.5912	1375	1155
1/2	3	1.500	5.784	1.7352	1500	1260
1/2	3 1/4	1.625	6.266	1.8798	1625	1365
1/2	3 1/2	1.750	6.748	2.0244	1750	1470
1/2	3 3/4	1.875	7.230	2.1690	1875	1575
1/2	4	2.000	7.712	2.3136	2000	1680
3/4	1	.750	2.892	.8676	750	630
3/4	1 1/2	1.125	4.338	1.3014	1125	945
3/4	2	1.500	5.784	1.7352	1500	1260
3/4	2 1/2	1.875	7.230	2.1690	1875	1575
3/4	3	2.250	8.676	2.6118	2250	1890
3/4	3 1/2	2.625	10.122	3.0366	2625	2260
3/4	4	3.000	11.568	3.4704	3000	2520

The Aluminum Company of America recommends 1200 amperes per square inch for the smaller bars and 500 for the largest.

Cabinets.—Metal cabinets only are used in connection with conduit systems. Cabinets are obtainable in four thicknesses of steel, viz., 16, 14, 12, and 10 U.S. Standard gauge, equal to 1/16, 5/64, 7/64, and 9/64 inches respectively. The thin metal is used only for the smaller boxes, and the heavy for the large ones. The depth of cabinets is usually great enough to allow door to close with small switches in any position, and the large ones thrown way back. For necessary dimensions, see *Cut-outs, Panel Boards,* or *Switches.* Where conduits enter all from one end, a wiring gutter space equivalent to about ¼ square inch for each circuit of number 14 twin conductor should be allowed. Cabinets should be provided to enclose all cut-outs. If practicable, locate them so as to reduce likelihood of rubbish being stored in them to a minimum. To locate switches outside of cut-out cabinets is good practice. In ordering cabinets note the following points: Wood or metal. Wall or flush mounting. With or without lining. With or without wiring gutter. Thickness of steel desired. Over-all dimensions of cut-outs, panel board, or switch. Inches of back wiring pocket. Inches of side wiring pocket. Spring hinges or not. Type of handle or lock. Side on which hinge must be. Finish and nature of door.

Candle Power.—This term is rather loosely used and has no very definite meaning, unless qualified by one of the following terms: Apparent candle power; equivalent candle power; mean lower hemispherical candle power; mean horizontal candle power; maximum candle power. The candle power of no lamp is the same in all directions.

Canopies.—The number of lamps to be used for the illumination of outlines in canopies is usually governed by the design of the canopy. The best effect, where outline lighting is to be installed, is obtained from many small lamps of low intrinsic brilliancy. Keep lamps and sockets out of the weather. Fixture canopies must be insulated wherever an insulating joint is called for on fixture.

Carbons.—For life of carbons with various types of arc lamps, see *Arc Lamps.* The upper carbon is usually the positive, and for projecting arcs is larger than the lower. The positive carbon holds its heat longer than the negative. If carbons are too large, the arc will travel around them. With direct current, the upper or positive carbon is consumed twice as fast as the other. Flaming arc carbons contain special materials in the core, and the color of the arc is governed by this material.

Car Houses.—A main switch is usually provided by which all wires in the car house can be cut off. Where a car house contains many sections it is better to provide a switch for each section. The illumination of car houses is usually by series incandescent lighting.

Carriage Calls.—These are usually made up in the form of electric signs, and located above canopies of theatres and hotels. They consist of a large number of monograms and require a large number of wires to be run to them. Outdoor wires should be run in water-tight conduit system. If armored cable is used outdoors it must be lead-covered insulation.

Cathode.—The cathode is the negative pole. This term is used in connection with batteries and electrolytic devices, mostly.

Ceiling Fans.—These must never be fastened rigidly, but in such a manner as to allow them to find their own "centers" when running. Not more

than 660 watts may be connected to one circuit. One fan to 400 or 500 square feet floor space is common practice.

Celluloid is highly inflammable, and must never be used exposed to heat or flame. Where a transparent medium of a similar appearance is needed, gelatine is used.

Cement when wet is a good conductor and may easily cause grounds.

Centers of Distribution.—In most cases the location of centers is governed by other conditions than economy of copper, and is dictated by the desire of the user. Where, however, free choice of location is given, the following tabulation showing the relative number of circular mils for each branch circuit of 660 watts at 110 volts will be of use. The table shows that with small mains, and especially three-wire systems, the amount of copper in the mains may be much less than in the branch circuits, and that it will be more profitable to run mains into the area to be served. This advantage grows less with larger mains. Branch circuits require 8214 circular mils per circuit of 660 watts.

The theoretical requirements per 660 watts for mains supplying centers is given below:

TABLE VIII

Mains B. & S.	2 Wire	3 Wire
14	3286	2460
12	3957	2968
10	5000	3752
8	5693	4270
6	6325	4744
5	7227	5426
4	7200	5397
3	7914	5934

Chandeliers.—No part of any chandelier should be less than six feet two inches above floor. The usual

height ranges between this and seven feet. In theatres and similar places where chandeliers hang very high, arrangement should be made for either raising or lowering to admit of lamp renewals. For large chandeliers special permission to use 1320-watt circuits can usually be obtained.

Chemical Works.—Before undertaking work in such places, investigate the nature of fumes, and chemicals used, with reference to effect upon copper and insulating materials, especially metal conduits, if considered.

Choke Coils.—These are used mostly in connection with lightning arresters. They must be as well insulated as the circuit wires to which they are connected.

Churches.—Some of the large churches require a lighting equipment similar to that of theatres. In choir lofts and at altars, pockets for special lights are often required. Indirect lighting is very useful in churches, as the light should be kept out of the line of vision of the speaker as well as the audience. From two to three foot candles are necessary. Emergency lighting should also be provided.

Circuit Breakers are much more sensitive than fuses. Many of them are so constructed as to allow a considerable overload for a short time, and the length of this time is adjustable. Circuit breakers should ordinarily not be set more than 30 per cent above the rated carrying capacity of the wire they are to protect.

Coils.—The coils of a magnet must be connected so as to form a continuous spiral.

Coloring Lamps.—Coloring and frosting of lamps reduces the light from 30 to 50 per cent. Amber coloring reduces the light about 20 per cent, while green and red take up from 50 to 90 per cent, according to the density and shade. Prepared color-

ing materials can be had at all supply stores. A few amber-colored lamps are sometimes mixed in with white lights to give a warmer glow to the light.

Color of Light Sources.—

Moore tube (carbon dioxide gas)............White
Intensified arc ....White
Magnetite arc ....White
Open arc ....Nearly white
Tungsten lamp ....Nearly white
Tungsten lamp, gas-filled.................White
Nernst lamp ....Nearly white
Enclosed arc (short arc).............Bluish white
Tantalum lamp ....Pale yellowish white
Gem lamp ....Pale yellowish white
Carbon lamp ....Pale yellowish white
Regenerative flame arc....................Yellow
Flaming arc.......Variable with different carbons
Mercury lamp (glass tube)...........Bluish green
Enclosed arc (long arc)......Bluish white to violet
High sun ....White
Low sun............................Orange red
Skylight ....Bluish white
Welsbach mantle ....Greenish white
Common gas burner...........Pale orange yellow
Kerosene lamp ....Pale orange yellow
Candle ....Orange yellow

TABLE IX

Comparison of Fahrenheit and Centigrade Thermometers

Fah.	Cent.	Fah.	Cent.	Fah.	Cent.	Fah.	Cent.	Fah.	Cent.
212	100	165	73.8	118	47.7	71	21.6	24	— 4.4
211	99.4	164	73.3	117	47.2	70	21.1	23	— 5.0
210	98.8	163	72.7	116	46.6	69	20.5	22	— 5.5
209	98.3	162	72.2	115	46.1	68	20.0	21	— 6.1
208	97.7	161	71.6	114	45.5	67	19.4	20	— 6.6
207	97.2	160	71.1	113	45.0	66	18.8	19	— 7.2

Fah.	Cent.	Fah.	Cent.	Fah.	Cent.	Fah.	Cent.	Fah.	Cent.
206	96.6	159	70.5	112	44.4	65	18.3	18	— 7.7
205	96.1	158	70.0	111	43.8	64	17.7	17	— 8.3
204	95.5	157	69.4	110	43.3	63	17.2	16	— 8.8
203	95.0	156	68.8	109	42.7	62	16.6	15	— 9.5
202	94.4	155	68.3	108	42.2	61	16.1	14	—10.0
201	93.8	154	67.7	107	41.6	60	15.5	13	—10.5
200	93.3	153	67.2	106	41.1	59	15.0	12	—11.1
199	92.7	152	66.6	105	40.5	58	14.4	11	—11.6
198	92.2	151	66.1	104	40.0	57	13.8	10	—12.2
197	91.6	150	65.5	103	39.4	56	13.3	9	—12.7
196	91.1	149	65.0	102	38.8	55	12.7	8	—13.3
195	90.5	148	64.4	101	38.3	54	12.2	7	—13.8
194	90.0	147	63.8	100	37.7	53	11.6	6	—14.4
193	89.4	146	63.3	99	37.2	52	11.1	5	—15.0
192	88.8	145	62.7	98	36.6	51	10.5	4	—15.5
191	88.3	144	62.2	97	36.1	50	10.0	3	—16.1
190	87.7	143	61.6	96	35.5	49	9.4	2	—16.6
189	87.2	142	61.1	95	35.0	48	8.8	1	—17.2
188	86.6	141	60.5	94	34.4	47	8.3	0	—17.7
187	86.1	140	60.0	93	33.8	46	7.7	— 1	—18.3
186	85.5	139	59.4	92	33.3	45	7.2	— 2	—18.8
185	85.0	138	58.8	91	32.7	44	6.6	— 3	—19.4
184	84.4	137	58.3	90	32.2	43	6.1	— 4	—20.0
183	83.8	136	57.7	89	31.6	42	5.5	— 5	—20.5
182	83.3	135	57.2	88	31.1	41	5.0	— 6	—21.1
181	82.7	134	56.6	87	30.5	40	4.4	— 7	—21.6
180	82.2	133	56.1	86	30.0	39	3.8	— 8	—22.2
179	81.6	132	55.5	85	29.4	38	3.3	— 9	—22.7
178	81.1	131	55.0	84	28.8	37	2.7	—10	—23.3
177	80.5	130	54.4	83	28.3	36	2.2	—11	—23.8
176	80.0	129	53.8	82	27.7	35	1.6	—12	—24.4
175	79.4	128	53.3	81	27.2	34	1.1	—13	—25.0
174	78.8	127	52.7	80	26.6	33	0.5	—14	—25.5
173	78.3	126	52.2	79	26.1	32	.0	—15	—26.1
172	77.7	125	51.6	78	25.5	31	—0.5	—16	—26.6
171	77.2	124	51.1	77	25.0	30	—1.1	—17	—27.2
170	76.6	123	50.5	76	24.4	29	—1.6	—18	—27.7
169	76.1	122	50.0	75	23.8	28	—2.2	—19	—28.3
168	75.5	121	49.4	74	23.3	27	—2.7	—20	—28.8
167	75.0	120	48.8	73	22.7	26	—3.3		
166	74.4	119	48.3	72	22.2	25	—3.8		

To convert degrees Centigrade into Fahrenheit, if the temperature given is above zero, multiply by 1.8

and add 32. If it is below zero multiply also by 1.8, but if this product is less than 32, subtract it from 32; if more, subtract 32 from it. To convert Fahrenheit into Centigrade, if the temperature given is above zero, subtract 32 and divide the remainder by 1.8; if below zero, add 32 and divide by 1.8.

Concentric Wire.—Concentric wires are seldom used except in mines and similar places. Such a wire fully insulated would require more insulating material and be more bulky than the ordinary duplex wire. The concentric wire recently put upon the market has only one wire insulated. The other wire is a metal sheath which entirely surrounds the inner wire and its insulation. The sheath must always be thoroughly grounded.

Condensers must be enclosed in noncombustible cases and installed with the same precautions as the wires of the system to which they attach. Condensers are usually rated in microfarads, and a condenser of two or three microfarads is considered quite large.

Conduits.—Conduit installations materially reduce the fire hazard, but to some extent increase the minor troubles. They produce many grounds and short circuits, but confine the trouble. Careful workmanship, especially at junction and outlet boxes, will reduce such troubles to a minimum. Install conduits so they will drain, and avoid their use in wet places unless lead-encased wires are used. Skilled conduit workers avoid the use of elbows with small wires as much as possible. The following tables (X and XI) give the sizes of conduits recommended by the National Electrical Contractors' Association of the United States in connection with various sizes and numbers of wires. These recommendations are based on actual tests and can be relied upon.

TABLE X

Standard sizes of conduits for the installation of wires and cables as adopted and recommended by The National Electrical Contractors' Association of the United States and the N. E. Code.

Conduit sizes are based on the use of not more than three 90° elbows in runs taking up to and including No. 10 wires; and two elbows for wires larger than No. 10. Wires No. 8, and larger, are stranded.

B. & S. Gauge	Approx. Diameter of Wire	One Wire in a Conduit — Diam. Int.	Ext.	Two Wires in a Conduit — Diam. Int.	Ext.	Three Wires in a Conduit — Diam. Int.	Ext.	Four Wires in a Conduit — Diam. Int.	Ext.
14	18/64	½	.84	½	.84	½	.84	¾	1.05
12	20/64	½	.84	¾	1.05	¾	1.05	¾	1.05
10	24/64	½	.84	¾	1.05	¾	1.05	1	1.31
8	28/64	½	.84	1	1.31	1	1.31	1	1.31
6	30/64	½	.84	1	1.31	1¼	1.66	1¼	1.66
5	31/64	¾	1.05	1¼	1.66	1¼	1.66	1¼	1.66
4	32/64	¾	1.05	1¼	1.66	1¼	1.66	1½	1.90
3	34/64	¾	1.05	1¼	1.66	1¼	1.66	1½	1.90
2	36/64	¾	1.05	1¼	1.66	1½	1.90	1½	1.90
1	40/64	¾	1.05	1½	1.90	1½	1.90	2	2.37
0	44/64	1	1.31	1½	1.90	2	2.37	2	2.37
00	48/64	1	1.31	2	2.37	2	2.37	2½	2.87
000	52/64	1	1.31	2	2.37	2	2.37	2½	2.87
0000	55/64	1¼	1.66	2	2.37	2½	2.87	2½	2.87
250,000	58/64	1¼	1.66	2½	2.87	2½	2.87	3	3.50
300,000	62/64	1¼	1.66	2½	2.87	2½	2.87	3	3.50
400,000	67/64	1¼	1.66	3	3.50	3	3.50	3½	4.00
500,000	73/64	1½	1.90	3	3.50	3	3.50	3½	4.00
600,000	80/64	1½	1.90	3	3.50	3½	4.00		
700,000	86/64	2	2.37	3½	4.00	3½	4.00		
800,000	89/64	2	2.37	3½	4.00	4	4.50		
900,000	93/64	2	2.37	3½	4.00	4	4.50		
1,000,000	97/64	2	2.37	4	4.50	4	5.00		
1,250,000	109/64	2½	2.87	4½	5.00	4½	5.00		
1,500,000	117/64	2½	2.87	4½	5.00	5	5.56		
1,750,000	128/64	3	3.50	5	5.56	5	5.56		
2,000,000	133/64	3	3.50	5	5.56	6	6.62		
Duplex Wires									
14	34/64	½	.84	¾	1.05	1	1.31	1	1.31
12	36/64	½	.84	¾	1.05	1	1.31	1¼	1.66
10	38/64	¾	1.05	1	1.31	1¼	1.66	1¼	1.66

TABLE XI

Standard sizes of conduits for the installation of wires and cables.

3 Wire Convertible System			3 Wire Convertible System		
2 Wires B. & S.	1 Wire	Size Conduit	2 Wires B. & S.	1 Wire	Size Conduit
14	10	¾	00	350,000	2½
12	8	¾	000	400,000	2½
10	6	1	0000	550,000	3
8	4	1	250,000	600,000	3
6	2	1¼	300,000	800,000	3
5	1	1¼	400,000	1,000,000	3½
4	0	1½	500,000	125,000	4
3	00	1½	600,000	1,500,000	4
2	000	1½	700,000	1,750,000	4½
1	0000	2	800,000	2,000,000	4½
0	250,000	2			

Single Wire Combination.

Number of single No. 14 wires in one conduit. Straight run; no elbows. Special permission is required.

	Conduit Size
3 No. 14 rubber covered double braid...........	½
5 No. 14 rubber covered double braid...........	¾
10 No. 14 rubber covered double braid...........	1
18 No. 14 rubber covered double braid...........	1¼
24 No. 14 rubber covered double braid...........	1½
40 No. 14 rubber covered double braid...........	2
74 No. 14 rubber covered double braid...........	2½
90 No. 14 rubber covered double braid...........	3

Signal Systems.

Straight runs; no elbows.

No. Wires	B.& S.		Conduit Sizes
10	16	Lt. ins. fixture wire..........	½
20	16	Lt. ins. fixture wire..........	¾
30	16	Lt. ins. fixture wire..........	1
70	16	Lt. ins. fixture wire..........	1¼
90	16	Lt. ins. fixture wire..........	1½

No. Wires	B.& S.		Conduit Sizes
150	16	Lt. ins. fixture wire..........	2
18	18	Lt. ins. fixture wire..........	½
30	18	Lt. ins. fixture wire..........	¾
40	18	Lt. ins. fixture wire..........	1
100	18	Lt. ins. fixtrue wire..........	1¼
130	18	Lt. ins. fixture wire..........	1½
200	18	Lt. ins. fixture wire..........	2

Telephone Circuits. Not more than two 90° Elbows.

No. 19 braided and twisted pair switchboard or desk instrument wires.

No. Pairs	Conduit
3	½
6	¾
10	1
16	1¼
25	1½
35	2

No. 20 braided and twisted pair switchboard or desk instrument wires.

No. Pairs.	Conduit
5	½
10	¾
15	1
25	1¼
35	1½
50	2

Conduits and Wires.—Two sides of the smallest rectangular enclosures that will contain a given number of wires are: $(D \times a) + \frac{D}{2}$ and $D \times b \times 86$. D being the diameter of the wire, a the number of wires in longest row, and b the number of rows.

The nearer square this enclosure can be made, the greater the economy of material. The greatest number of wires that can be placed in a rectangular enclosure is $\left(\frac{L}{D} - \frac{1}{2}\right) \times \left(\frac{H}{D \times .86}\right)$

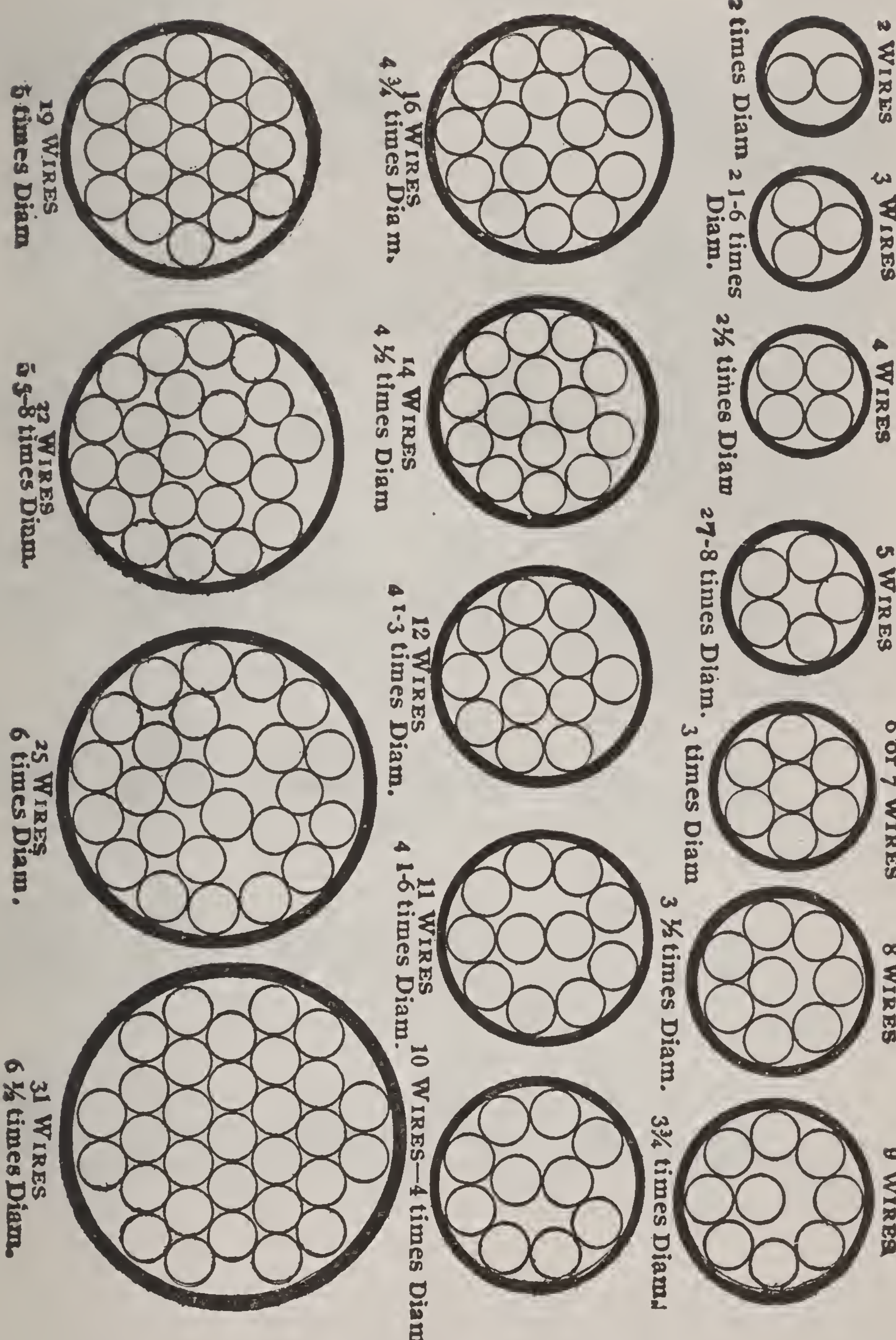
L being the length of the enclosure, H the height, and D the diameter of the wire.

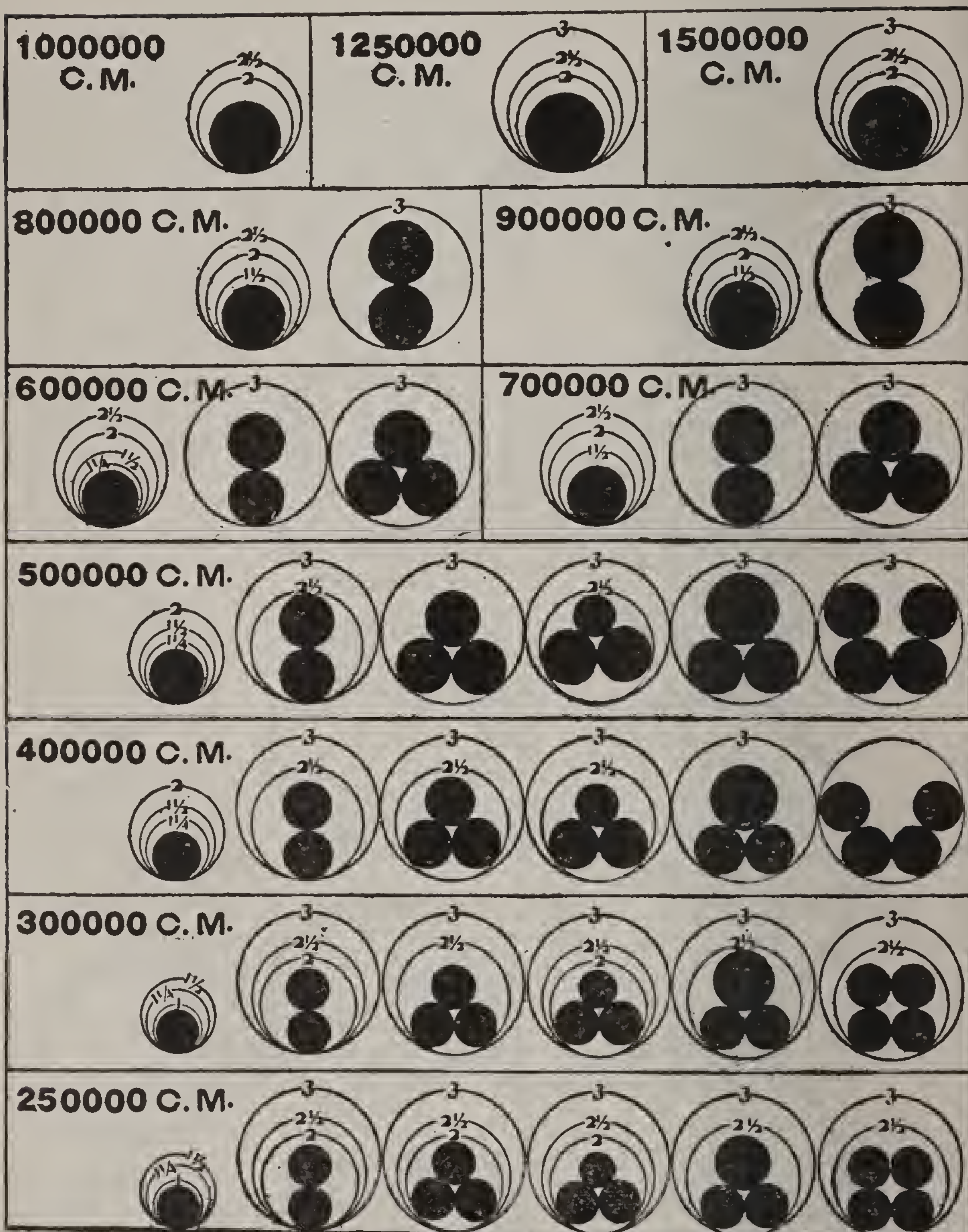
This formula is only approximate and in using it all fractions obtained by $\frac{L}{D}$ and $\frac{H}{D \times .86}$ must be dropped.

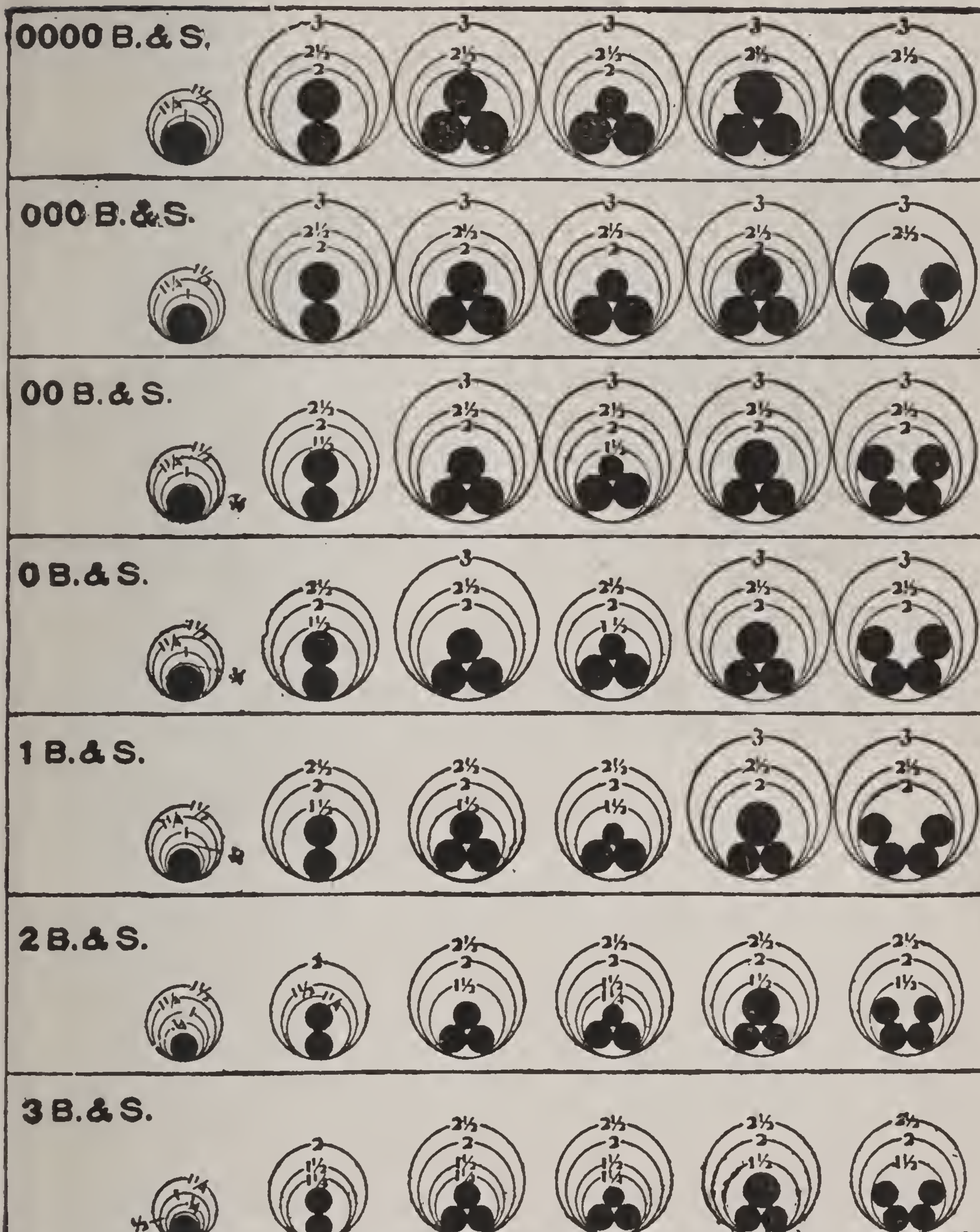
Example.—Given an enclosure 6 inches long and 2 inches high, how many wires can it hold, the diameter of each wire being .7? 6 divided by .7 equals 8.6. Dropping the .6 and subtracting $\frac{1}{2}$, we have 7.5 for the first factor. Next, .7 times .86 equals .602; 2 divided by this equals 3.3; dropping the .3, we now have to multiply the 7.5 by 3, which equals 22.5, or 22 wires.

For circular enclosures no general formula can be given because the percentage of waste space varies greatly with different wires. The first chart may be used to determine the smallest conduit that will enclose a certain number of wires. This chart shows graphically how nearly different numbers of wires fill out circular spaces. To use this chart, multiply diameter of wire by the number given in connection with circle containing the requisite number of wires. This will give the smallest diameter of tube or conduit that will receive these wires. How much larger the conduit to be used must be depends upon circumstances. The number and nature of bends, nature of insulation, flexibility of wire, as well as temperature and inspection requirements, must be taken into consideration.

The charts illustrate the relative spaces occupied by the different conduits, viz.: 3″, $2\frac{1}{2}$″, 2″, $1\frac{1}{2}$″, $1\frac{1}{4}$″, 1″, etc., and the wires considered. The sizes of conduits are marked in the various circles and each horizontal row pertains to one size of wire, with exception of the 4th and 5th in each row and a few at the top of one of the charts. The 4th shows a neutral wire of half the carrying capacity, and the 5th of double the carrying capacity of the outside wires. The different sizes of conduit given in each case will enable one to judge the most appropriate size to be used under different circumstances. The wires shown are all double braid stranded cables.


2 WIRES
2 times Diam
3 WIRES
2 1-6 times Diam.
4 WIRES
2½ times Diam
5 WIRES
2 7-8 times Diam.
6 or 7 WIRES
3 times Diam
8 WIRES
3 ⅓ times Diam.
9 WIRES
3¾ times Diam.
16 WIRES
4 ¾ times Diam.
14 WIRES
4 ½ times Diam
12 WIRES
4 1-3 times Diam.
11 WIRES
4 1-6 times Diam.
10 WIRES—4 times Diam.
19 WIRES
5 times Diam
32 WIRES
5 5-8 times Diam.
25 WIRES
6 times Diam.
31 WIRES
6 ⅓ times Diam.


1000000
C. M.
1250000
C. M.
1500000
C. M.
800000 C. M.
900000 C. M.
600000 C. M.
700000 C. M.
500000 C. M.
400000 C. M.
300000 C. M.
250000 C. M.


0000 B. & S.
000 B. & S.
00 B. & S.
0 B. & S.
1 B. & S.
2 B. & S.
3 B. & S.

In the preceding pages are given the conduit sizes recommended by the National Electrical Contractors' Association of the United States. These should be followed as far as they apply.

Contacts.—The standard materials for mounting contacts are slate, marble, porcelain, and glass. Where these are liable to breakage, other materials are allowed, but they should always be submitted to inspection departments for approval. A surface contact of one square inch for each 75 amperes is good practice for knife-switches and similar devices.

Controllers.—Methods of motor and light control are numerous. Lights are usually controlled by cutting resistance into the mains. A certain controller is suitable only for a certain number of lights requiring a certain amperage. The reduction of voltage is equal to the product of the amperes times the resistance, and the effect upon the lights is greater than indicated by the drop in voltage. The speed of motors may be altered by cutting resistance into the mains, altering the field connections, arranging taps of different voltages, and connecting armatures in multiple or series.

Cooking.—Almost any kind of cooking can be accomplished electrically, but the expense is higher than with gas. It is best to be honest and advise customers correctly about these things than to cause disappointment. The advantages are convenience and rapidity of results with many of the devices.

Cooper-Hewitt Lamps (Mercury Vapor).—These lamps may be obtained for either alternating or direct-current use, and for 110 or 220 volts. The light given out is of a greenish hue, and gives a ghastly effect to faces and hands. Many persons object to working under it, while others seem to like it. The efficiency of the lamp compares favor-

ably with others; it is easy to operate, and the light is practically shadowless. With alternating currents the light flickers somewhat, and is said to give a deceptive appearance to some surfaces. Not more than one lamp should be installed on one circuit. Use double-pole switches and avoid plug cut-outs for 220 volts. Current sent through direct-current lamps in wrong direction will ruin tubes. Where inflammable gases exist, the sparking of some of the lamps is dangerous. The life of a tube is now claimed to be 5000 hours. The current ranges from 3.5 to 2.0 amperes for different types, and the efficiency is given as from 0.51 to 0.64 watts per mean lower hemispherical candle power. The light is mostly thrown downward.

Copper weighs about 556 pounds per cubic foot; its specific gravity is about 8.9, and it melts at 1196 degrees Fahrenheit. The tensile strength of annealed copper may be taken as about 35,000 pounds per square inch, and that of hard drawn copper as about 55,000.

Cross Currents pass between A.C. generators, and also between synchronous motors when they are operating in parallel and not perfectly in phase. These currents heat the wires and overload the machines unnecessarily.

Cut-outs.—In connection with installations served by central stations, the type of cut-out and fuse preferred by that company should be installed. This will usually obtain free fuse renewals. The installation of cartridge-type fuses is not advisable except in establishments where a competent electrician is always on duty.

The dimensions of several types of cut-outs are given below.

TABLE XII

Paiste Panel Cut-Outs (See Figure 2).

125 Volt Sizes. Capacity of Switches 30 Amperes

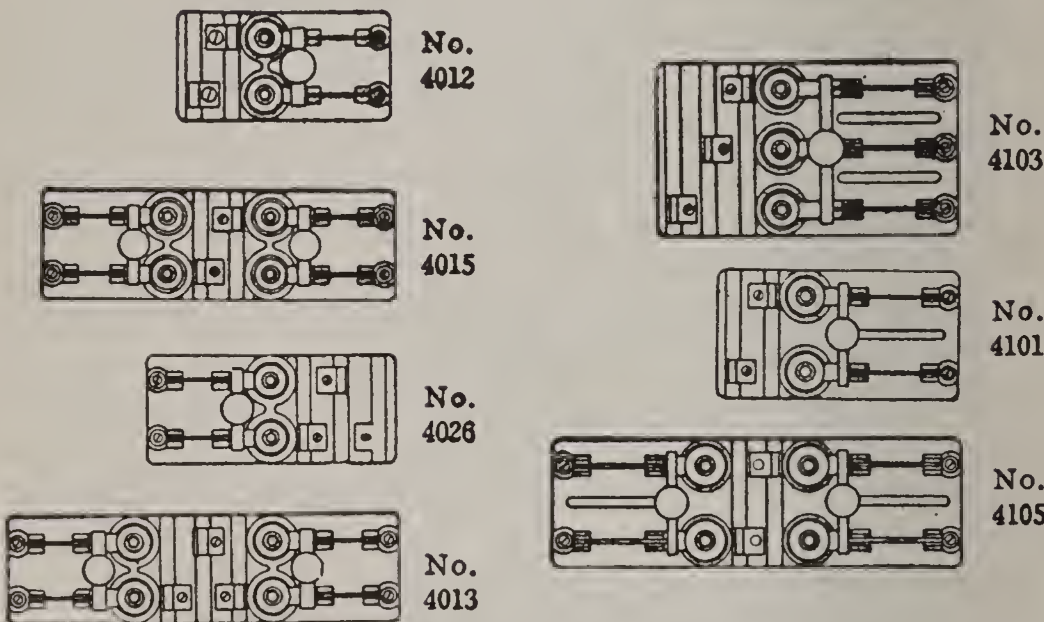


Figure 2.—Paiste Panel Cutouts.

Cat. No.	Main	Branches	Width (inches)	Length (inches)
4012	2-Wire	Single, 2-Wire	3⅛	5⅞
4015	2-Wire	Double, 2-Wire	3	10⅛
4026	3-Wire	Single, 2-Wire	3¼	7¼
4013	3-Wire	Double, 2-Wire	3⅛	10⅞
4103	3-Wire	Single, 3-Wire	5	8⅝

250 Volt Sizes. Capacity of Switches 30 Amperes

=4101	2-Wire	Single, 2-Wire	3¾	7
=4105	2-Wire	Double, 2-Wire	3¾	11¾

TABLE XIII

Dimensions for Plug Cut-Outs (See Figure 3).

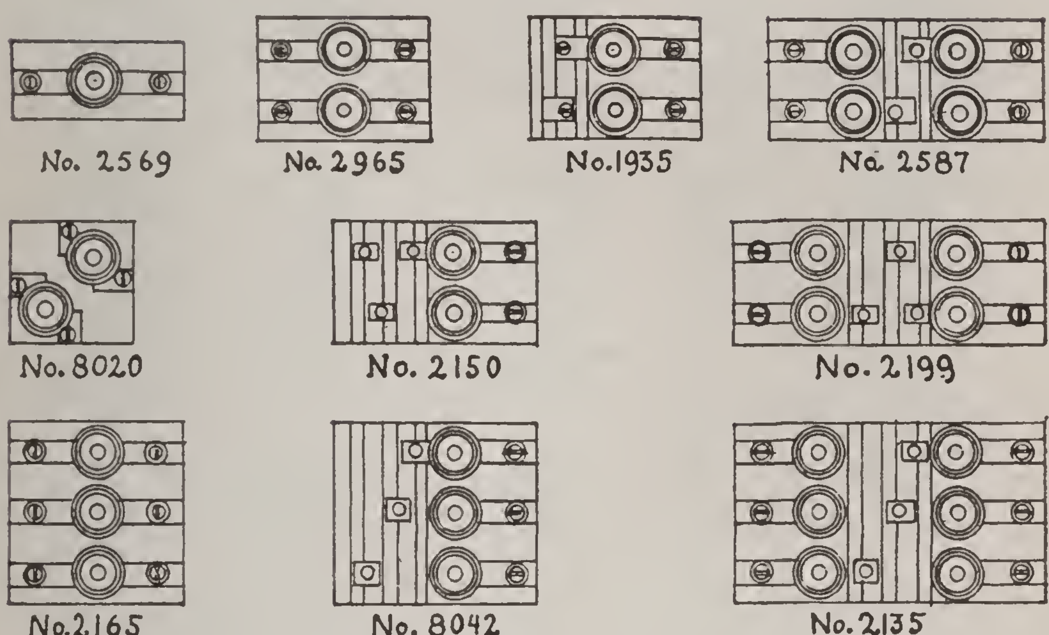


Figure 3.—Plug Cutouts.

Cat. No.	Length (inches)	Width (inches)	Height (inches)
2569	2¾	2	$1\frac{31}{64}$
2965	2½	$3\frac{1}{16}$	$1\frac{29}{64}$
2165	$2\frac{9}{16}$	4½	$1\frac{29}{64}$
8020	3⅜	3⅜	1½
1935	$3\frac{19}{32}$	$3\frac{1}{16}$	$1\frac{29}{64}$
2587	$5\frac{3}{16}$	3	$1\frac{31}{64}$
2150	4⅞	3	$1\frac{17}{32}$
2199	$6\frac{5}{16}$	$2\frac{15}{16}$	$1\frac{31}{64}$
8042	$4\frac{13}{32}$	$4\frac{13}{32}$	$1\frac{23}{32}$
2135	6⅞	$4\frac{7}{16}$	$1\frac{21}{32}$

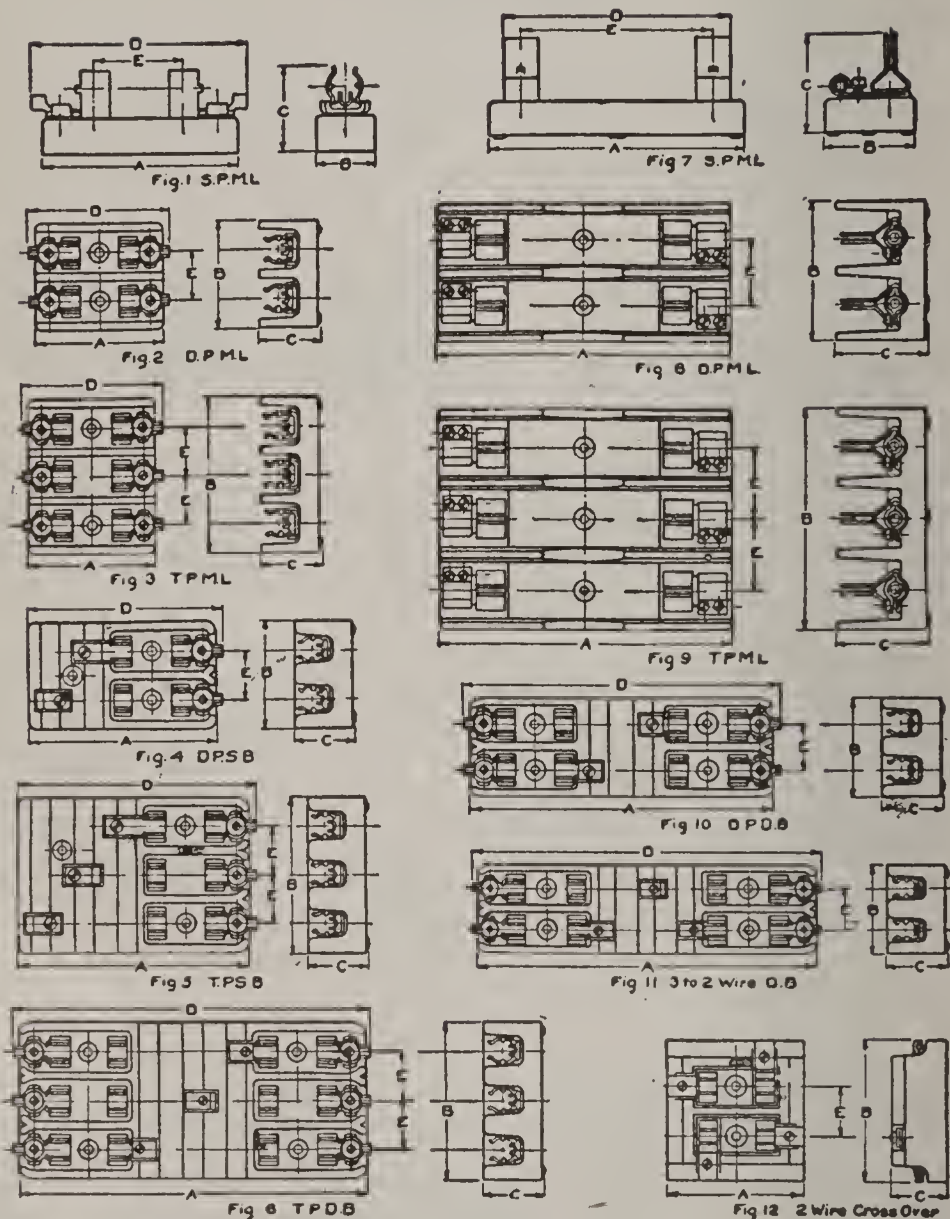


Figure 4.—D. & W. Cutouts.

TABLE XIV

Dimensions of D. & W. 250 Volt Cut-Outs (See Figure 4).

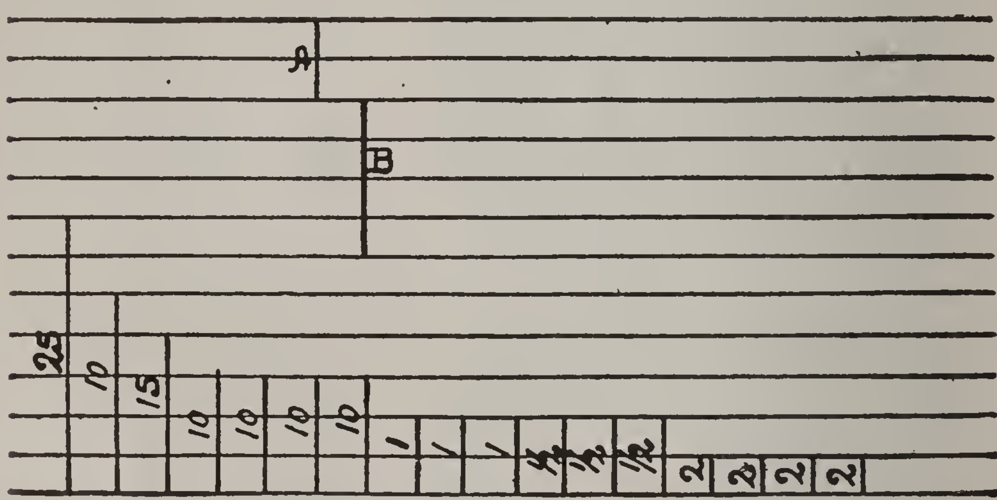
Amperes	Fig.	A	B	C	D	E
0-30	1	$3\frac{3}{8}$	1	$1\frac{7}{16}$	$3\frac{3}{8}$	$1\frac{1}{2}$
0-30	2	$3\frac{5}{16}$	$2\frac{3}{4}$	$1\frac{9}{16}$	$3\frac{5}{16}$	$1\frac{1}{4}$
0-30	3	$3\frac{5}{16}$	4	$1\frac{9}{16}$	$3\frac{5}{16}$	$1\frac{1}{4}$
0-30	4	$4\frac{7}{8}$	$2\frac{3}{4}$	$1\frac{9}{16}$	$4\frac{7}{8}$	$1\frac{1}{4}$
0-30	5	6	4	$1\frac{9}{16}$	6	$1\frac{1}{4}$
0-30	10	$7\frac{3}{4}$	$2\frac{3}{4}$	$1\frac{9}{16}$	$7\frac{3}{4}$	$1\frac{1}{4}$
0-30	6	$8\frac{15}{16}$	$4\frac{1}{16}$	$1\frac{9}{16}$	$8\frac{15}{16}$	$1\frac{1}{4}$
0-30	11	$8\frac{15}{16}$	$2\frac{7}{8}$	$1\frac{9}{16}$	$8\frac{15}{16}$	$1\frac{1}{4}$
0-30	12	$3\frac{1}{2}$	$3\frac{5}{8}$	$1\frac{7}{16}$	$3\frac{1}{2}$	$1\frac{1}{4}$
31-60	1	$4\frac{7}{8}$	$1\frac{3}{8}$	$1\frac{15}{16}$	$5\frac{9}{16}$	$2\frac{3}{8}$
31-60	2	$4\frac{3}{4}$	$3\frac{7}{16}$	$1\frac{7}{8}$	$5\frac{9}{16}$	$1\frac{9}{16}$
31-60	3	$4\frac{3}{4}$	5	$1\frac{7}{8}$	$5\frac{9}{16}$	$1\frac{9}{16}$
31-60	4	$6\frac{5}{8}$	$3\frac{7}{16}$	$1\frac{7}{8}$	$6\frac{15}{16}$	$1\frac{9}{16}$
31-60	5	8	5	$1\frac{7}{8}$	$8\frac{5}{16}$	$1\frac{9}{16}$
31-60	10	$10\frac{11}{16}$	$3\frac{5}{8}$	$2\frac{1}{4}$	$11\frac{5}{8}$	$1\frac{11}{16}$
31-60	6	12	$5\frac{5}{16}$	$2\frac{1}{4}$	$12\frac{7}{8}$	$1\frac{11}{16}$
31-60	11	12	$3\frac{11}{16}$	$2\frac{1}{4}$	$12\frac{7}{8}$	$1\frac{11}{16}$
61-100	7	$6\frac{1}{2}$	$2\frac{1}{4}$	$2\frac{9}{16}$	$6\frac{5}{8}$	$4\frac{7}{8}$
61-100	8	$8\frac{1}{8}$	$4\frac{3}{16}$	$2\frac{5}{16}$	$8\frac{1}{8}$	$1\frac{15}{16}$
61-100	9	$8\frac{1}{8}$	$6\frac{1}{8}$	$2\frac{5}{16}$	$8\frac{1}{8}$	$1\frac{15}{16}$
101-200	7	$7\frac{3}{4}$	$2\frac{7}{8}$	$3\frac{1}{8}$	$8\frac{1}{4}$	$5\frac{3}{4}$
201-400	7	$9\frac{1}{4}$	$3\frac{3}{8}$	$4\frac{1}{16}$	$10\frac{1}{4}$	$6\frac{3}{4}$
401-600	7	11	$3\frac{1}{2}$	$4\frac{3}{8}$	$12\frac{3}{8}$	$8\frac{1}{8}$

Delta Connection.—This method of connection is used only with three-phase a.c. currents. If the connection of a generator is changed from "star" to "delta," its current will be increased 1.73 times

for the same power delivery. If it is changed from "delta" to "star," its e.m.f. will be increased 1.73 times. A synonymous term for delta is "mesh."

Demand Factor.—At present it is customary among inspection bureaus to demand conductor capacity equivalent to the whole connected load operating at its maximum capacity. Experience, however, has shown that in many cases this leads to a great waste of copper.

In very many installations it has been found that not over 20 per cent of the connected load is ever in



Demand Factor Chart.

use at the same time. Tables of demand factors applicable to many classes of service have been worked out and are in existence. But as far as the authors are aware, these are all arranged from the standpoint of the central station engineer and are hardly applicable to individual installations. As a matter of fact, the authors have failed to find any two installations, even in the same line of business, quite alike.

INDIVIDUAL MOTORS

Many motors are now designed and rated to carry a certain overload, usually 25 per cent, for a short time. This fact should be taken into account wherever it seems necessary. Whenever motors are designed for a short time rating, instead of for continuous use, it seems but right that the conductors be chosen with the same length of time in view. Insofar as the heating of conductors is concerned, it is unnecessary to pay any attention to the ordinary starting current. The only justification for the excessive carrying capacity usually demanded for individual motors, lies in a possible necessity to take care of overloads.

GROUPS OF REGULARLY REVERSING MOTORS

A graphic representation of current values in a series of cycles of operation of a reversible motor operating a large washing machine is given in Figure 4b. In connection with such motors, it is quite usual to reverse without giving the armature time to come to rest. The reversed current through the armature must first bring the machinery to rest and then start it in the opposite direction. The majority of such motors reverse at intervals of 10 or 12 seconds and the average peak current lasts about one second.

In this connection it will be well to note that, in order to give this study a practical value, we must take a course about midway between absolute accuracy and haphazard guess work. The heating effect of various kinds of motor loads cannot be accurately determined without the use of graphic current charts

and these are seldom available at the time the installation is made. The contractor and the inspector are thus, in the majority of cases, compelled to judge by the rated h. p. of the motors required. In order, therefore, to make these tables of general use to the public, the carrying capacity of conductors required

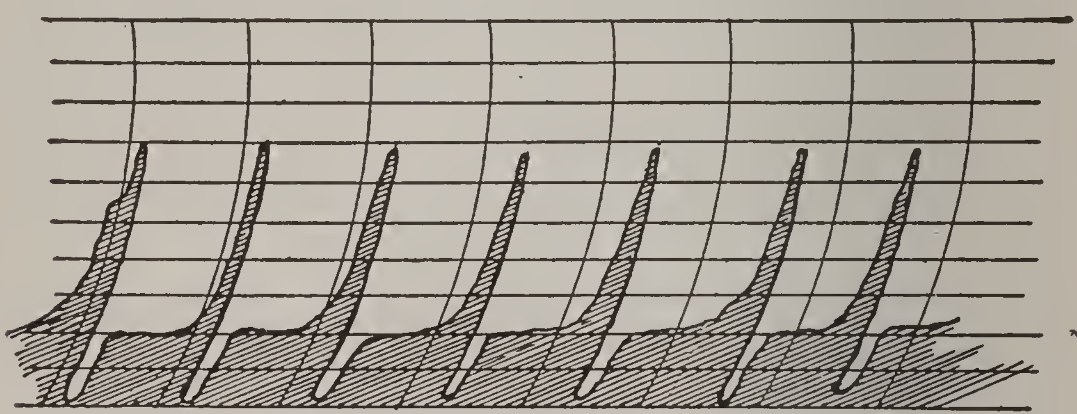


Figure 4b

must be based upon the h. p. intended to be installed. It is principally for this reason that the following table has been arranged in the form given.

The table gives factors which express the ratio of the h. p. equivalent of intermittent or fluctuating currents to the heating equivalent of the same currents. The h. p. value of a fluctuating current (voltage assumed constant) is proportional to the average sum of all the ordinates of a curve representing it. The heating effect of the same current is proportional to the r. m. s. value of the same ordinates. Thus, if we divide the r. m. s. value of a certain fluctuating current by its h. p. value, we shall obtain a factor by which we may multiply the h. p. delivered by a motor in such service in order to find the amperage for which conductor capacity should be provided to guard against overheating.

At the top of the table we have the various percentages of time of minimum and peak currents. In the first vertical row we have various percentages of peak currents expressed in terms of the minimum current used. In this form we may use the factors in connection with the rated h. p. of the motors, provided we know, in a general way, the approximate ratio of the minimum to the peak currents required by the fluctuating load.

As an example: If we have a motor reversing regularly and requiring a peak current five times as great as its running current, and this during half of the time of each cycle, we look where the lines pertaining to 50 per cent peak and minimum current time cross the line pertaining to the 500 per cent peak, and find there the factor 1.21, which indicates that the amperage to be provided for must be 1.21 times that called for by the h. p. rating of the motor.

TABLE

Percent time of peak current.		10	20	30	40	50	60	70	80	90
Percent time min. current....		90	80	70	60	50	40	30	20	10
Percent peak load in terms of min. load..	200%	1.04	1.05	1.06	1.06	1.05	1.04	1.04	1.04	1.01
	300%	1.12	1.15	1.15	1.14	1.12	1.10	1.07	1.05	1.02
	400%	1.22	1.25	1.23	1.21	1.17	1.13	1.10	1.07	1.03
	500%	1.31	1.34	1.30	1.26	1.21	1.16	1.11	1.07	1.03
	600%	1.41	1.42	1.37	1.29	1.23	1.18	1.12	1.08	1.04
	700%	1.50	1.50	1.40	1.32	1.25	1.19	1.13	1.09	1.04
	800%	1.59	1.54	1.44	1.35	1.27	1.20	1.15	1.09	1.04
	900%	1.67	1.59	1.47	1.37	1.28	1.21	1.15	1.09	1.04
	1000%	1.74	1.63	1.50	1.39	1.29	1.22	1.15	1.09	1.04

The factors here given are correct for single motors and are based on the worst possible condition under which a group of motors can operate; viz., all peaks superimposed. This is a condition which may at times

be attained, but if a large group of motors is considered, the chance of its recurrence is exceedingly small.

With these considerations in view, we deduce the following formula to find the fraction of the total time during which the peaks of all the motors in use are likely to be superimposed:

$$A^b$$

In this formula, A represents the fraction of the time of a cycle of operation during which the peak is in use, and b the number of motors in use. In the case of laundry motors of the characteristics shown in Figure 4b, the peaks, when once coincident, will remain so for some length of time or until one or more have been stopped and the combination broken. In the case of elevator motors the combination will almost immediately be broken.

GROUPS OF REVERSING MOTORS WITH VARIABLE TIME INTERVALS

In many machine shops the planers are equipped with reversing motors. Some very clever systems of control have been worked out and in some of these the carriage is made to return at a high rate of speed after making the cut. The length of time during which such a motor moves in either direction is variable and the power required by the forward and return strokes is also variable. The periodicity, as well as the relative amount of current, vary and are governed by the work in hand.

Since there is no permanent regularity about any of the operations, no exact forecast as to what will happen at any particular time can be made. A study

of the conditions as illustrated in Figure 4c will, however, assist materially in judging what the current demands of a group of such motors may be at times.

In the figure we have five motors, denoted by black circles, in operation and reversing regularly at intervals of 12, 6, 8, 4 and 9 seconds. An inspection of the figure will show at a glance that, with any num-

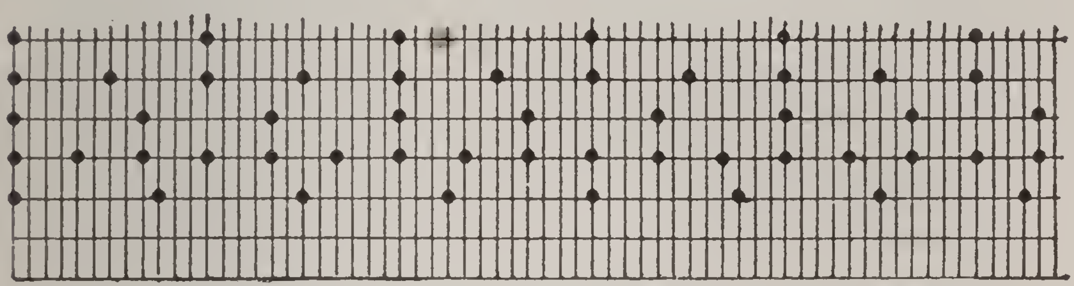


Figure 4c

ber of motors, if they start in synchronism, the time of coincidence of the peak of all of them will be proportional to the least common multiple of all of their time intervals. In this case that number is 72; hence, at intervals of 72 seconds these motors will all come into synchronism as far as their peaks are concerned. Their minima of current will, of course, also come into synchronism regularly.

If they do not start in synchronism, those starting at time intervals which form a multiple of their own time, remote from that of other motors, will work into synchronism and out of it in a perfectly regular manner, just as will those shown in the figure. Those that start at different time intervals, however, will not.

As an example, if the motor having a period of 6 seconds starts either 1, 2, 3, 4, 5, 7, 8, 9, 10 or 11 seconds after the other, it will never superimpose its

peak entirely upon that of the other, although a part of it may overlap. It must, however, be borne in mind that the motor having the shortest periods governs the chances of falling into step. A motor having a period of 4, for instance, will have only one chance in 4 of missing regular synchronism of peaks with other motors having periods of 8 or 12. With motors on this kind of work then, we may be certain that there will be coincidence of peaks at times. In connection with motors of this kind it will be safe to use about the average multipliers given in the table, the average being determined from the characteristics of the different motors.

PASSENGER ELEVATOR AND SIMILAR MOTORS

In the kind of service here considered, the current is either entirely on or off. If calculations are to be based upon current or power charts the equivalent current of a cycle of operations should be determined by the r. m. s. method. The formulae and the tables herewith furnished, however, are so arranged that, for general purposes, we need merely know the rated h. p. of the whole group and the relative time of the on and off periods.

In the preliminary operation of finding the current required it is to be assumed that the motors are delivering their rated capacity continuously, regardless of the nature of their rating. The formula given below is also independent of the number of motors and the demand factor obtained is a function of the relative on and off times of the motors, which is assumed to be the same for all.

A conductor is used to the best advantage with

reference to heating when subjected to a steady current flow. Hence, if another conductor be called upon to transmit an equivalent amount of energy with intermittent service, the carrying capacity of the second conductor must be correspondingly increased. If the load is of such a nature that the conductor is idle half of the time, it must carry double current during the other half of the time. As the heating is proportional to the square of the current, it follows that a double current during half time is equivalent in heating effect to $\sqrt{2}$ times the normal current used continuously. The same relation holds for all other time divisions and this will allow us to find the value of a steady current, to be denoted by I, which will be the equivalent of any regularly intermittent current of the nature here considered by the formula as given below:

$$\sqrt{\frac{t}{t'}} \times i = I$$

where i is the theoretical current based on the total motor rating, t the fraction or percentage of time in a cycle of operation during which the motor is using this current, and t' the time of a complete cycle of operation. This formula will give us a multiplier, virtually a demand factor, by which we can find the current having an equivalent heating effect to that required by the motors under the assumption that they are all working under the worst possible condition, i. e., all motors taking their maximum current at the same instant.

The factors calculated according to the formula as applying to the various percentages of time dur-

ing which the current is in use, are given below. The upper line gives the percentage of time during which current is used, and the lower line gives the multiplying factors.

Percentage of Time.......	10	20	30	40	50	60	70	80	90
Factors	.32	.45	.55	.66	.71	.78	.84	.89	.95

GROUPS OF MOTORS OF INDISCRIMINATE CHARACTERISTICS

This classification embraces all kinds of motors as usually found in shops and factories. There are two ways of arriving at the probable demand factor of such groups. One way consists of consulting tables made up from experiences with similar installations. This method has the great disadvantage that it is almost impossible to find two installations near enough alike to warrant very accurate comparisons. Such tables are given further on, but should be used only as general guides and the final determination made only after making a careful analysis of the installation.

A simple method of analyzing a motor installation and determining its demand factor is as follows: Take any piece of ordinary ruled paper and number as many lines as there are hours of the day to be considered. Let these lines be horizontal. Next draw as many lines vertically across them as there are motors to be considered. Also place each line so that in position and length it may cover the hours of the day during which the motors are thought to be in use.

There are two ways in which such a representation can be made. If the motors have no fixed time at which they run, their running time may be laid out at the bottom of the figure; the main point being that

the lines give a fair idea of the proportionate running time per day. If the stopping and starting intervals are not too short, a series of such lines, representing the estimated number of starts, may be used.

If any of the motors are used only during certain hours of the day, the line pertaining to these motors may be placed in the horizontal lines pertaining to the hours of the day, as for instance *A* and *B* in the figure. These two motors never interfere with each other, but do occasionally come in at the same time with some of the other motors plotted at the bottom of the line.

Department Stores.—Such places usually require large quantities of power for illumination, electric signs, and motors. The demand factor for lighting is very close to 100 per cent. If economy is not too much insisted upon, a bountiful circuit capacity should be provided. This will allow brilliant illumination wherever it is needed. As department stores contain nearly all of the goods handled in other stores, hints on illumination of special places should be looked up under the corresponding headings—dry goods stores, jewelry, etc. As there are usually large areas visible from any one place, good appearance demands some uniform arrangement of fixtures. If this does not provide sufficient light for certain goods in show cases, local illumination is provided in the cases. If branch circuit capacity for five watts per square foot is provided, it will enable very brilliant illumination of spots without overloading circuits and not interfere with the frequent changes which are made. The capacity of general mains need not be greater than two watts per square foot on the most important flows.

Depreciation.—Depreciation must be duly considered in dealing with any form of apparatus. The depreciation is governed entirely by the useful life of the device, but this in turn is governed by the amount of wear and tear which cannot be repaired for from time to time; obsolescence, possibly inadequacy after a time, or probable cessation of business. Depreciation should not be confused with maintenance, to which should be charged all mishaps which do not permanently lessen the natural useful life of the apparatus. From 10 to 20 per cent is often charged to depreciation, but it is better to estimate it carefully in each case unless a parallel case is well understood.

Desk Lighting.—The illumination of desks by individual lamps is never to be advised, except in the case of individuals with very poor eyesight or in locations where desks are far apart or used but a few hours per day. Where individual desk lighting is provided, the cost of energy may sometimes be lower, but the first cost of installation, and also maintenance, is always high. There is, further, always a considerable fire hazard, and all of these offset the saving in energy to a large extent. A general and fairly shadowless illumination also adds much to the efficiency of clerks. The following table shows the comparative cost of proper general illumination as compared with local for desks of various spacing. It is assumed that a general illumination of $1\frac{1}{4}$ watts per square foot is provided, and that at each desk a 25-watt lamp is also used, while the general illumination with which this desk lighting is compared is obtained through the medium of the most efficient large wattage lamps at present on the market. One watt per square foot will give good general illumination, which will need to be helped out by local lighting only for persons with

weak eyes. Where local desk lighting is resorted to the wattage requirements will be about as follows:

Av. sq. ft. per desk....	20	25	30	35	40	45	50
Total watts per sq. ft..	1.5	1.25	1.08	0.96	0.87	0.80	0.75

It will be noted that where desks are close together the general illumination is not only the easiest installed but also the cheapest to operate. If the desks are used only a small part of the time the local illumination will be the cheaper. Lamps used for desk lighting should either be frosted or encased in diffusing globes.

Diamagnetic.—Zinc, antimony, bismuth, and certain other metals are repelled when placed between the poles of strong magnets, and are said to be diamagnetic. Metals which are attracted by magnetism are said to be paramagnetic.

Dielectric.—Any substance which is an insulator and allows electrostatic induction to take place through its mass. Usually taken as synonymous with insulation.

Dry Kilns.—Such places are too hot for rubber-covered wire. Use asbestos-covered. Place cut-outs and switches outside.

Eddy Currents.—Useless currents which are produced in the iron of pole pieces, etc., subject to motion in a magnetic field, or to the influence of coils in which a fluctuating current exists. They cause a waste of energy and heat the metal.

Efficiency.—The efficiency of motors, transformers, and other similar translating devices is found by dividing the output by the input. In connection with sources of electric illumination the term *efficiency* has an entirely different meaning. The efficiency of such devices is spoken of as a certain

number of watts per candle power. In this case, the higher the efficiency, the more uneconomical is the lamp. See *Motors* and *Illumination* for practical applications.

Egg Candling.—One light must be provided for each workman, and it should be located about waist high. The wires should be run at this height so as to avoid use of long cords. The light is always made adjustable, and is encased in a small metallic hood with a small opening.

Electric Braking.—This is also sometimes termed "dynamic braking." If an electric motor is disconnected from its source of supply, and its armature circuit closed while the armature is still in motion, it will generate current and consume power, and may be brought to rest very quickly in this manner. Where the necessary provisions for this purpose are installed this method of braking is very successful.

Electrolysis.—Nearly all electrolysis is due to the fact that piping and other metallic structures near a ground return system of electrical distribution afford a return circuit of such low resistance as compared to the return circuit provided, that a large part of the current returns over the piping. It is impossible to prevent electrolysis entirely except by insulating the return wires. The troubles may, however, be materially reduced. The current does damage only where it leaves the pipes or other structures which it has entered, and the damage is in proportion to the amperes carried. The methods used for lessening electrolysis are the following:

1. Protection of structures by concrete or other forms of insulation, or keeping them as far as possible from ground return circuits. Insulation of piping is not advisable; it is likely to concentrate the trouble at spots where it is poor.

2. Bonding pipes, etc., so as to prevent current which has once entered them from leaving, except at predetermined places, and then never to earth.

3. Negative boosters have been suggested, but have not been extensively tried. A negative booster is a low-voltage dynamo connected into the return circuit in such a manner as to draw current from the rails and earth and deliver it back to the station.

4. Reinforcing the rails, etc., by large conductors, thus increasing the conductivity of the return, and lowering the p. d. between the rails and the station.

In most cities ordinances mention the difference in potential which may be allowed to exist between any two points on the return wires. In Chicago it is provided that all uninsulated electrical return circuits must be of such current-carrying capacity and so arranged that the difference of potential between any two points on the return circuit will not exceed the limit of twelve volts, and between any two points on the return 1000 feet apart within a one-mile radius of the City Hall will not exceed the maximum limit of 1 volt, and between any two points on the return 700 feet apart outside of this one-mile radius limit will not exceed the limit of 1 volt. In addition thereto, a proper return conductor system must be so installed and maintained as to protect all metallic work from electrolysis damage. The return current amperage on pipes and cable sheaths must not be greater than 0.5 amperes per pound-foot for caulked cast iron pipe, 8.0 amperes per pound-foot for screwed wrought iron pipe, and 16.0 amperes per pound-foot for standard lead or lead alloy sheaths of cables.

All insulated return current systems must be equipped with insulated pilot wire circuits and volt-

meters, so that accurate chart records will be obtainable daily, showing the difference of potential between the negative bus-bars in each station and at least four extreme limits on the return circuit in its corresponding feeding district. Also with recording ammeters, insulated cables, and automatic reverse load and overload circuit breakers which will record and limit the maximum amperes drained from all the metallic work (except the regular return feeders) to less than 10 per cent of the total output of the station. Figuring on the basis of the average resistance of cast iron, wrought iron, and lead, the above amperages will exist with the following difference of potential per running foot, and will be independent of the thickness or size of pipe: Cast iron, 0.000711 volt per foot; measurements must be taken on solid pipe and not across any joint. Wrought iron, 0.001568 volt per foot; measurement to be taken as above. Lead sheaths, 0.007497 volt per foot; as joints in lead sheaths are always soldered and wiped, no attention need be paid to them. The lower amperage for the iron piping is specified because joints will usually be found of higher resistance than the piping, and at each joint current is likely to leave piping and enter it again just beyond.

The proper treatment of electrolysis may require all four methods outlined above. The method most to be recommended in a general way is that of reinforcing the return conductors sufficiently to limit the difference of potential as prescribed.

The following table shows the size of copper conductors necessary with rails of various weights per yard to reduce electrolysis to $\frac{1}{2}$, $\frac{1}{3}$, and $\frac{1}{4}$, etc.; the specific resistance of the rails being taken as 10 times that of copper, and the resistance of bonds as negligible.

TABLE XV

Showing c. m. of copper necessary to reduce p. d. of electrolysis to the fraction of its original value given.

Weight of Rails Per Yard	Circular Mils of Rail	1-2	1-3	1-4
40	4,950,000	495,000	990,000	1,485,000
45	5,600,000	560,000	1,120,000	1,680,000
50	6,230,000	623,000	1,246,000	1,869,000
60	7,500,000	750,000	1,500,000	2,250,000
70	8,770,000	877,000	1,754,000	2,631,000
80	9,900,000	990,000	1,980,000	2,970,000
90	11,200,000	1,120,000	2,240,000	3,360,000
100	12,500,000	1,250,000	2,500,000	3,750,000

Weight of Rails Per Yard	Circular Mils of Rail	1-5	1-6	1-7	1-8
40	4,950,000	1,980,000	2,475,000	2,970,000	3,465,000
45	5,600,000	2,240,000	2,800,000	3,360,000	3,920,000
50	6,230,000	2,492,000	3,115,000	3,738,000	4,361,000
60	7,500,000	3,000,000	3,750,000	4,500,000	5,250,000
70	8,770,000	3,508,000	4,385,000	5,262,000	6,039,000
80	9,900,000	3,960,000	4,950,000	5,940,000	6,930,000
90	11,200,000	4,480,000	5,600,000	6,720,000	7,840,000
100	12,500,000	5,000,000	6,250,000	7,500,000	8,750,000

For a comprehensive treatment of electrolysis a map of the return circuits and adjacent piping should be made. Tests determining p. d. and direction of current should be made, and results marked upon the map. In many cases currents will be found in opposite direction at the same point at different times. In estimating the current strength from p. d. noted between track and piping the distance of the latter from the track must be taken into consideration. If this is small a low p. d. may deliver considerable current. Often the trouble can be reduced sufficiently by running comparatively short lengths of heavy copper. In testing p. d.'s it is best to use a sensitive galvanometer. Such an instrument may be calibrated with reference to a milli-volt meter.

TABLE XVI

The table below shows the approximate amperage per milli-volt p.d. per foot which will be found in the various kinds and sizes of piping and sheaths given.

Cast Iron, Inside Diam.	Wt., Per Ft.	Average Amperes	Wrought Iron, Inside Diam.	Wt., Per Ft.	Average Amperes	Lead Sheaths, ⅛" Outside Diam.	Amperes Approx.
3	16	12	½	.87	4½	1.26	5
4	22	15	¾	1.15	5½	1.50	6
6	35	25	1	1.70	8	1.58	6
8	50	37	1¼	2.25	11	1.65	6.6
10	67	50	1½	2.75	14	1.68	6.9
12	87	65	2	3.60	18	1.72	7.0
14	110	82	2½	5.80	30	1.78	7.1
16	135	102	3	7.65	40	1.84	7.2
18	165	123	3½	9.00	48	1.90	7.5
20	190	141	4	11.0	57	1.95	7.7
24	255	190	4½	12.5	66	1.98	7.9
30	370	275	5	15.0	80	2.00	8.0
36	500	375	6	19.0	100	2.05	8.2
42	665	500	7	24.0	125	2.10	8.4
48	850	635	8	29.0	155	2.15	8.6
54	1,050	775	9	34.0	180	2.19	8.8
60	1,300	970	10	41.0	220	2.21	8.9
72	1,575	1,200	11	46.0	250	2.24	9.0
84	1,850	1,400	12	51.0	275	2.32	9.3

Electrolyte is the name given to the solution used in storage batteries and other batteries.

Electromagnets.—The magnetic flux is equal to the magnetomotive force divided by the reluctance. The magnetomotive force is the product of current times number of turns of wire and is known as ampere turns. The reluctance of the iron of all well designed magnets is very low but that of the air gap is high, so that roughly speaking we can judge the total reluctance by the air gap. In any given case the magnetic flux is approximately proportional to the current strength up to a point at which the iron

becomes nearly saturated. After this the increase is slow until the point of full saturation is reached and after this it is very slow.

To increase the magnetization (e. m. f. being fixed) we must increase the size of wire; winding more turns of the same wire upon a spool simply decreases the current required for a given magnetization but does not alter the magnetization itself. The self-induction and the sparking are proportional to the square of the number of turns of wire. The heating is proportional to the square of the current used. The heating of the coils sets the limit of the current which may be used. A radiating surface of from 1 to 3 square inches per watt consumed in the coil is usually provided. One watt per square inch will heat the coil very much if it is in use continuously. The possible traction of electromagnets is about 200 lbs. per square inch for good annealed wrought iron, and 75 for cast iron. This, however, varies widely with the quality of iron used. In laboratory experiments as high as 1,000 lbs. per square inch has been obtained. Single phase a-c. magnets do not give a constant pull but two and three phase magnets are very serviceable. The "chattering" of single phase magnets can be lessened by a "shading coil." Lifting magnets are extensively used. They are built with the two poles concentric and the material to be lifted constitutes the armature. Permanent magnets are used only in small sizes.

USEFUL FORMULAS AND TABLES

In the following formulas it is assumed that the wires lie squarely over one another in the coil, each wire fully occupying a space equal to the square of its diameter. As in most coils some insulating medium is placed between the different layers, this is about the condition which exists in practice.

The symbols used in the formulas are as follows:

d = diameter of wire, in inches, over insulation.
l = length of wire, on spool, in inches.
nt = number of turns.
r = resistance of one foot of wire.
rs = radiating surface.
B = diameter of core and insulation, in inches.
D = diameter over outside of completed winding, in inches.
L = length of winding space on spool, in inches.
N = depth of winding from core to outside, in inches.
W = weight of wire.
a, c, k = constants for use in the formula, given in the tables below. Each constant has a different value for each size and kind of wire used.

Number of turns in a given spool (see Figure 5):

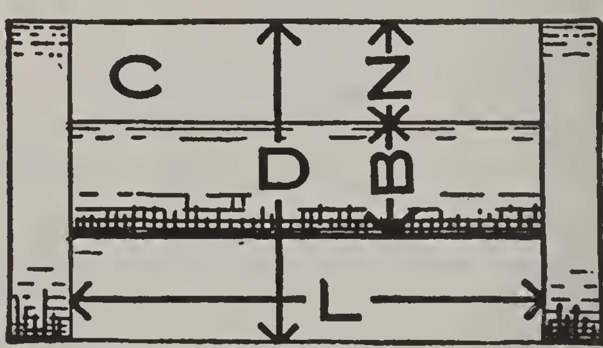


Figure 5.

$$nt = \frac{L \times N}{d^2}$$

Diameter of wire to give a certain number of turns:

$$d = \sqrt{\frac{L \times N}{nt}}$$

Cross-section of winding space, or $L \times N$, necessary to accommodate a certain number of turns of a given wire:

$L \times N = d^2 \times nt.$

Length of wire on a given spool:

$l = (D^2 - B^2)\, L \times k.$ See table below for value of k.

Weight of wire on a given spool:

$W = (D^2 - B^2)\, L \times c.$ See table below for value of c.

Resistance of wire on a given spool:

$R = (D^2 - B^2)\, L \times a.$ See table below for value of a.

Radiating surface for a given spool:

$rs = D \times 3.14 \times L.$

TABLE XVII

CONSTANTS.

	k — Constant for Length			c — Constant for Weight			a — Constant for Resistance		
B. & S. Gauge	Double Cotton	Single Cotton	Single Silk	Double Cotton	Single Cotton	Single Silk	Double Cotton	Single Cotton	Single Silk
20	40.9	50.4	56.7	.137	.162	.177	.415	.512	.576
21	50.4	64.1	72.7				.638	.812	.920
22	60.2	78.0	89.7				.97	1.257	1.445
23	68.3	89.7	104.7				1.387	1.82	2.08
24	83.6	113.5	135.	.1115	.149	.169	2.14	2.91	3.46
25	97.2	135.	163.				3.14	4.36	5.27
26	114.	163.	202.				4.65	6.65	8.24
27	135.	202.	255.				6.94	11.75	13.1
28	148.	226.	291.	.0845	.122	.148	9.60	14.62	18.82
29	182.	291.	387.				14.85	23.7	31.6
30	201.	334.	454.				20.7	34.4	46.8
31	226.	387.	542.				29.36	50.25	70.4
32	255.	454.	655.	.0687	.1045	.132	41.8	74.4	107.2
33	291.	542.	812.				60.33	114.5	168.
34	334.	655.	1023.				87.1	170.5	266.5
35	354.	712.	1140.				116.2	234.	374.8
36	387.	811.	1340.	.0492	.0825	.1115	160.	335.5	555.
37	422.	897.	1582.				220.5	468.	806.
38	457.	1023.	1825.				308.	674.	1192.
39	496.	1170.	2165.				412.	972.	1795.
40	532.	1300.	2525.	.038	.0615	.0888	557.	1360.	2645.

TABLE XVIII

Round Cotton-covered Magnet Wire

American Steel & Wire Co.

Coarse Sizes

Size B. & S.	Diameter Inches	Allowable Variation Either Way in Per Cent.	Rated Area in Cir. Mils.	Single Cotton Covered Approximate Values: Outside Diameter Inches	Single Cotton Covered Approximate Values: Feet per Pound	Double Cotton Covered Approximate Values: Outside Diameter Inches	Double Cotton Covered Approximate Values: Feet per Pound
0	0.3249	½ of 1	105,625	.333	3.1	.339	3.1
1	.2893	½ of 1	83,694	.297	3.9	.303	3.9
2	.2576	½ of 1	66,358	.266	5.	.272	4.9
3	.2294	¾ of 1	52,624	.237	6.2	.243	6.2
4	.2043	¾ of 1	41,738	.212	7.8	.218	7.8
5	.1819	¾ of 1	33,088	.190	9.9	.196	9.9
6	.1620	¾ of 1	26,244	.170	12.5	.176	12.4
7	.1443	¾ of 1	20,822	.152	15.7	.158	15.6
8	.1285	1	16,512	.136	19.8	.142	19.6
9	.1144	1	13,087	.121	24.9	.125	24.7
10	.1019	1	10,384	.108	31.4	.113	31.1
11	.0907	1	8,226	.097	39.5	.102	39.1
12	.0808	1¼	6,528	.087	49.6	.092	49.2
13	.0720	1¼	5,184	.078	62.5	.083	61.7
14	.0641	1¼	4,108	.070	78.6	.075	77.5
15	.0571	1½	3,260	.063	98.9	.068	97
16	.0508	1½	2,580	.056	125	.060	122
17	.0453	1½	2,052	.050	157	.054	153
18	.0403	1½	1,624	.045	198	.050	192
19	.0359	1¾	1,288	.041	248	.045	240

ENAMELED MAGNET WIRE

Enamel insulation has a dielectric strength far in excess of silk or cotton covered wire. It will also withstand a much greater heat, as silk and cotton insulation will char at 270° Fahr., whereas enamel insulation will withstand 450° Fahr. without the slightest deterioration.

Another decided feature about enamel insulation is the economy of space where this material is used for coil windings, and it takes up much less space than the single silk insulation. This feature is a very important one, especially to manufacturers of electrical instruments and apparatus where space economy is essential.

TABLE XIX

Size B. & S.	Diam. Enam. Wire	Approx. Feet per Lb.	Approx. Turns per Sq. In.	Size B. & S.	Diam. Enam. Wire	Approx. Feet per Lb.	Approx. Turns per Sq. In.
16	....	126	359	29	.0122	2570	7900
17	....	159	447	30	.0109	3240	10000
18	....	201	567	31	.0097	4082	12620
19	....	253	715	32	.0087	5132	16020
20	.0337	320	885	33	.0077	6445	20400
21	.0302	404	1126	34	.0069	8093	25200
22	.0269	509	1400	35	.0062	10197	31900
23	.0241	642	1736	36	.0055	12813	40000
24	.0215	810	2160	37	.0049	16110	51600
25	.0192	1019	2770	38	.0044	20274	65700
26	.0171	1286	3460	39	.0039	25519	81600
27	.0153	1620	4270	40	.0035	32107	104000
28	.0136	2042	5400	..	....	....	....

TABLE XX

Table for Insulated Copper Wire. (Belden Manufacturing Co.)

B. & S. Gauge	Single Cotton, Total Insulation Thickness 4 Mils.		Double Cotton, Total Insulation Thickness 8 Mils.		Single Silk, Total Insulation Thickness 1¾ Mils.		Double Silk, Total Insulation Thickness 4 Mils.	
	Ohms per pound	Feet per pound	Ohms per pound	Feet per pound	Ohms per pound	Feet per pound	Ohms per pound	Feet per pound
20	3.15	311	3.02	298	3.24	319	3.18	312
21	4.99	389	4.72	370	5.12	403	5.03	389
22	7.88	488	7.44	461	8.15	503	7.96	493
23	12.44	612	11.7	584	12.92	636	12.65	631
24	19.55	762	18.25	745	20.50	800	19.95	779
25	30.8	957	28.45	903	32.50	1005	31.5	966
26	48.6	1192	44.3	1118	51.29	1265	49.7	1202
27	76.45	1488	68.8	1422	82.00	1590	78.3	1542
28	120.	1852	106.5	1759	129.00	1972	123.5	1917
29	188.5	2375	164.	2207	205.00	2570	194.	2485
30	294.6	2860	252.	2534	328.5	3145	306.5	2909
31	460.5	3800	384.5	2768	512.3	3943	477.	3683
32	716.	4375	585.	3737	810.0	4950	747.	4654
33	1117.	5390	880.	4697	1277.5	6180	1165.	5689
34	1720.	6580	1315.	6168	2018.	7740	1810.	7111
35	2642.	8050	1960.	6737	3175.	9680	2820.	8534
36	4060.	9820	2890.	7877	4970.	12000	4340.	10039
37	6190.	11860	4230.	9309	7940.	15000	6660.	10666
38	9440.	14300	6150.	10666	12320.	18660	10250.	14222
39	14420.	17130	8850.	11907	19200.	23150	15600.	16516
40	22600.	21590	12500.	14222	30200.	28700	23650.	21333

TABLE XXI

Table of Diameters (d) and Square of Diameters (d^2) for Insulated Copper Wire.

B. & S.	Double Cotton		Single Cotton		Single Silk	
	d	d^2	d	d^2	d	d^2
20	.040	.0016	.036	.001296	.034	.001156
21	.036	.0013	.032	.00102	.030	.0009
22	.033	.00109	.029	.00084	.027	.00073
23	.031	.00096	.027	.00073	.025	.000625
24	.028	.000784	.024	.000576	.022	.000484
25	.026	.000675	.022	.000484	.020	.0004
26	.024	.000575	.020	.0004	.018	.000324
27	.022	.000484	.018	.000324	.016	.000256
28	.021	.000441	.017	.000289	.015	.000225
29	.019	.00036	.015	.000225	.013	.000169
30	.018	.000324	.014	.000196	.012	.000144
31	.017	.000289	.013	.000169	.011	.000121
32	.016	.000256	.012	.000144	.010	.000100
33	.015	.000225	.011	.000121	.009	.000081
34	.014	.000196	.010	.000100	.008	.000064
35	.0136	.000185	.0096	.000092	.0076	.0000576
36	.013	.000169	.009	.000081	.007	.000049
37	.0124	.000155	.00845	.000073	.00645	.0000415
38	.012	.000143	.008	.000064	.006	.0000362
39	.0115	.000132	.0075	.000056	.0055	.0000303
40	.0111	.000123	.0071	.0000504	.0051	.000026

Elevators.—Electric motors are used direct connected or belted; in some cases they are used to pump water for hydraulic elevators. Motors should be capable of exerting a strong starting torque, and are generally compounded. Means are usually provided for cutting out the compound winding, or otherwise weakening the field to obtain high speeds. To prevent sparking at the brushes, commutating poles are frequently used. The ordinary commercial motor is seldom used for elevator service.

The methods of speed control with d.c. motors consist in weakening the field and cutting resistance out or in; dynamic braking is also used in some cases for slowing down. With a.c. motors wound rotors are often used.

Single phase as well as two and three phase motors are practicable, and variable speed motors are often employed. Hydraulic elevators require about 1.7 as much power as direct connected. A.-c. elevator motors under the same conditions require about 20 to 30 per cent more power than d.c. motors.

The H.P. required can be found by the formula

$$\text{H.P.} = \frac{l \times s}{33{,}000 \times e}$$

where l = unbalanced load in pounds, s = speed in feet per minute, e = combined efficiency of motor and elevator machinery. This is usually about 0.50.

The speed of freight elevators often runs as low as 65 to 85 feet per minute, while some passenger elevators run as fast as 700 feet per minute. As the load is always intermittent motors may be rated high, and the starting torque is from two to two and one-half times running torque.

The following table gives the H.P. required to lift various loads at speeds given; a combined efficiency of 50 per cent being assumed.

TABLE XXII

Table showing H. P. required to lift unbalanced loads at speeds given. Efficiency of 50 per cent assumed.

Speed in Feet Per Minute

Lbs.	75	100	125	150	200	250	300	400	500
1000....	4.5	6.1	7.6	9.1	12.1	15.1	18.2	24.2	30.2
1250....	5.7	7.6	9.5	11.4	15.2	19.0	22.8	30.4	38.0
1500....	6.8	9.1	11.4	13.6	18.2	22.8	27.2	36.4	45.6
1750....	7.9	10.5	13.3	15.8	21.0	26.6	31.6	42.0	53.2
2000....	9.1	12.1	15.2	18.2	24.2	30.4	36.4	48.4	60.8
2500....	11.3	15.1	19.0	22.6	30.2	38.0	45.2	60.4	76.0
3000....	13.6	18.2	23.7	27.2	36.4	47.4	54.4	72.8	94.8
3500....	15.9	21.2	27.5	31.8	42.4	55.0	63.6	84.8	110.0
4000....	18.2	24.2	30.4	36.4	48.4	60.8	72.8	96.8	121.6
4500....	20.4	27.3	34.2	40.8	54.6	68.4	81.6	109.2	136.8
5000....	22.7	30.3	38.0	45.4	60.6	76.0	90.8	121.2	152.0
6000....	27.2	36.4	45.4	54.4	72.8	90.8	108.8	145.6	181.6

Emergency Lighting.—This is usually required in churches, theatres and other places where large numbers of people congregate. The purpose is to provide a system of illumination which shall be in service if the main system should fail. In large cities the emergency lighting is supposed to be used during the entire time the audience is in the building. An entirely independent and separate service should be provided for it, and there should be no switches or fuses except those absolutely necessary.

Equalizers.—Equalizer wires are used in connection with two or more compound generators operated in parallel. All connections must be to the same terminal with series field. Wires should be led to switchboard, and connected to middle blade of switch. Arrange switch blades so that equalizer will be connected slightly ahead of other wire. The lower the resistance of the equalizer, the closer will be the regulation of the machines. Never connect ammeter on same side with equalizer.

Factors.—*Assurance Factor.*—This is the ratio of the voltage at which a wire or cable is tested to that at which it is to be used.

Demand Factor. (See *Demand Factor*).—This is the ratio or the maximum demand of any system, or part of a system, to the total connected load of the system, or of the part of the system under consideration.

Diversity Factor.—The diversity factor of any part of a system of distribution is the ratio of the sum of the maxima of the subdivisions to the maximum demand on the source of supply during some given time.

To find the diversity factor we divide the sum of the maxima of the consumers during a given period of time by the maximum registered at the source of supply during the same time. If all consumers use their maximum energy at the same instant the diversity factor is 1. A large diversity factor is a distinct advantage. In a central station system a certain diversity factor will be found to exist between the consumers maxima, and the transformer serving them; between the various transformers and the main serving them there will be another diversity factor; between the mains and their feeder still another will exist, and so on between mains, substations, transmission lines, and central station. The diversity factor of the last station is found by multiplying together all the other diversity factors.

Average diversity factors for a large central stations as given by Gear & Williams are:

Residence lighting. Diversity factor from 3.32 to 3.40. Commercial lighting. Diversity factor from 1.40 to 1.51. General power. Diversity factor from 1.39 to 1.60.

Load Factor.—The load factor is the ratio of the average load to the maximum load demanded by a

consumer, a group of consumers connected to a single transformer, a group of transformers, feeders, mains, transmission lines, substations, generators, or central stations. For each of these on the same system it has a different value which is found by dividing the average load by the maximum load. A low load factor is a disadvantage.

The following data are condensed from tables published by Gear & Williams in "Electric Central Station Distributing Systems."

Residence lighting.

Individual consumer's average load factor = 7%.

Transformer load factor = 23% to 24%.

Commercial lighting.

Average consumer's load factor = 10% to 13%.

Transformer load factor = 15% to 19%.

General power.

Average consumer's load factor = 15% to 21%.

Transformer load factor = 21% to 30%.

Plant Factor.—This is the ratio of the average load to the rated capacity of the power plant.

Power Factor.—The power factor is the ratio of the true power to the volt-amperes. In the case of sinusoidal voltage and current, the power factor is equal to the cosine of their difference in phase. The power factor is always less than unity and may be either lagging or leading.

Reactance Factor.—This is the ratio existing between the reactance of a circuit, and its ohmic resistance.

Reactive Factor.—The reactive factor expresses the ratio of the wattless volt-amperes to the total volt-amperes. It is equal to the reactance divided by the impedance, which is equal to the sine of the angle between the impressed voltage and the current.

Safety Factor.—The ratio of the strength of material to the load to which it is to be subjected. It is

common practice to use a safety factor of 4 or 5.

Saturation Factor.—The saturation factor of a machine is the ratio of a small percentage increase in the field excitation, to the corresponding increase in voltage thereby produced.

Factories.—It is an old custom to illuminate factories by means of small c. p. lamps distributed among machinery so as to give each workman in need of it one lamp. Since the advent of the large wattage tungsten, or Mazda lamps, this has been somewhat changed. The change has been further helped along by individual drive machinery which has eliminated the belting and shafting. Where the work is not particular, one 100 watt tungsten lamp, if kept clean, to every 200 or 300 square feet of floor surface will give good results. Where particular work is done this illumination must be helped out by a 15 watt local lamp. A general illumination has the advantage that it will not have to be changed every time a machine is moved, which frequently happens. Where individual lighting for machinery is to be provided it will be well to avoid placing lamps before the machinery is located; plans are seldom reliable. The mercury vapor lamp gives a very serviceable illumination for some purposes, but it is said that fine machine work is not well done under it; also because of the ghastly appearance is gives faces, many men do not like to work under it. Oil dissolves rubber very fast, and when flexible cord is used around machinery it is well to encase it in loom.

To avoid interference with open wires run them as far as possible between joists or along beams. Drop all lights from ceiling and never use floor pockets or side wall outlets. Make ample provision for glue pots and small portable motors.

(For hints on motors, see *Motors.*)

Fans.—(See *Ventilation.*)

Farad.—The practical unit of capacity. A condenser or conductor in which a charge of one coulomb (1 ampere for 1 second) produces a p. d. of one volt has a capacity of one farad. The farad is much too large for practical work, and micro-farads are used. A condensor of two or three micro-farads is quite large.

Faradic Current.—This term is used in therapeutics, and designates the current taken from an induction coil as distinguished from a galvanic or direct current.

Faure Plate.—In this type of storage battery plate, the active material is pasted onto the supporting material, instead of being *formed* there. This type of plate is used mostly for vehicles. It gives a maximum of capacity with a minimum of weight.

Feeders.—These are the wires which start from a central station, substation, or other center and feed a group or center from which mains supply translating devices. The term is always rather loosely used. There may be feeders and sub-feeders. A voltage of about 1,000 per mile of feeder length is customary.

Festoons.—Festoons to be strung across streets are usually wired with number 8 or 10 wire, and weatherproof sockets. As a rule they are supported in the center of the street, and swung from pulleys which allow of lowering for lamp renewals, etc. In order to allow for graceful hanging the wires should be from 1.3 to 1.6 times the width of street. Lights are usually spaced from 18 inches to two feet apart. At street intersections two festoons are often swung diagonally across, and in such a case the length of wire should be two times the width of street. The supporting cables from which the festoons are swung are attached to buildings and poles on opposite side of street and in many cases they must be run diagonally to find attachments which will allow the fes-

toon to come in its proper place. This often necessitates very long spans and requires strong cables. Three-eighths and half-inch steel cables are often used. Where festoons are swung over trolley lines strain insulators are used. Festoons for theatre work are made up of stage cable and weatherproof sockets; joints are staggered, and taped to prevent strain on joints.

Fiber.—This, in general, is a serviceable insulating material, but on account of the fact that it does not resist moisture, and swells and warps when wet, it is not approved for light and power voltages.

Field.—This term describes either a magnetic, or an electrostatic field. Field magnets are the electromagnets which produce the electric field in which the armature revolves. Field coils are the coils in which the magnetizing current circulates. A field rheostat is one which regulates the current in the field coils. A field of force is the space traversed by an electrostatic, or magnetic flux. The field windings of induction motors are those in which the rotating field is produced.

Fire Alarms.—May be either automatically, or manually operated. In the manual system a glass disk is usually broken to send in an alarm. In the automatic system a fuse opens, or closes a circuit and sends in the alarm. A system in which the current is constantly flowing is always preferable because it is always under test, and failure of any kind will send in an alarm. Means of testing without sending in alarms should be provided. The common fire alarm telegraph system consists of boxes containing notched wheels which are released when the box is pulled, and send in the code signal.

Fish Work.—For light and power voltages armored cable, or single rubber covered wires in circular loom are used; never use twin wire. When

one is alone on a fish job, a bell and battery connected to the fish wire with one pole, and to a coil of wire inserted in the hole at the other end with the other, is very useful. When the fish wire touches the other wire the bell will ring. Use a small chain for dropping and a spring wire for other work.

Fixtures.—The height of hanging varies from 6 feet 2 inches to 7 feet. The so-called art-domes are hung much lower, but they are a passing fad.

Memorandum of Fixture Work

	Name..................... Address....................	Room or Circuit Number					
Chandeliers	No. lights on each circuit......	....	....	....	....	....	....
	No. of beam lights...........	....	....	....	....	....	....
	No. of electric lights.........	....	....	....	....	....	....
	No. of gas lights............	....	....	....	....	....	....
	Style of finish..............	....	....	....	....	....	....
	Catalogue number...........	....	....	....	....	....	....
	Sketch number..............	....	....	....	....	....	....
	Kind of glassware..........	....	....	....	....	....	....
	Catalogue number...........	....	....	....	....	....	....
	Size of holders............	....	....	....	....	....	....
	Kind of sockets............	....	....	....	....	....	....
	Height lowest point above floor	....	....	....	....	....	....
	Size of gas stub............	....	....	....	....	....	....
Brackets	No. of elec. lights...........	....	....	....	....	....	....
	Kind of sockets.............	....	....	....	....	....	....
	No. gas lights..............	....	....	....	....	....	....
	Style of finish..............	....	....	....	....	....	....
	Catalogue number...........	....	....	....	....	....	....
	Sketch number..............	....	....	....	....	....	....
	Kind of glassware..........	....	....	....	....	....	....
	Catalogue number...........	....	....	....	....	....	....
	Height above floor..........	....	....	....	....	....	....
	Size gas stub	....	....	....	....	....	....
	No. switches................	....	....	....	....	....	....
	Kind of switch..............	....	....	....	....	....	....
	Style of finish..............	....	....	....	....	....	....

The standard height of brackets is from $5\frac{1}{2}$ to 6 feet above floor.

No fixture should ever be selected except with reference to the room in which it is to be hung, and it should be neither conspicuous for its expensiveness or cheapness.

Elaborate fixtures made up of cheap material should never be used; pretense is always abominable. Before installing, test each fixture for continuity, short circuits and grounds; move wires while

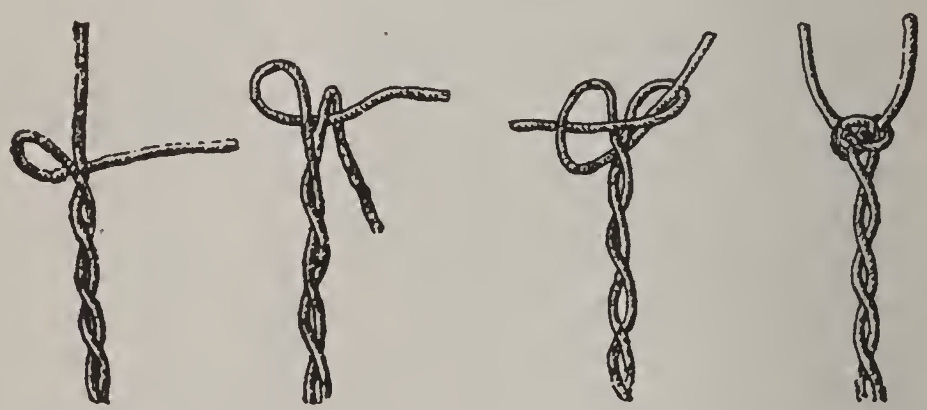


Figure 6.—Method of Tying Knots in Flexible Cord.

testing. The following memoranda will be of use in ordering fixtures:

Flashers on branch circuits usually operate single pole. In such a case one-half of the cut-outs may be located at flasher, the other half, if more convenient, in the sign. Although the flasher allows the use of only a part of the lights at a time, it is customary to run mains for the full requirements of all the lights.

Flat Irons constitute a considerable fire hazard and every precaution should be taken to install them safely. A pilot lamp is very useful. Provide extra flexible cord to help out the cord furnished with iron so the two will be long enough to allow iron to fall to the floor without straining fixture or other attachment. The common domestic flat irons weighing

from 3 to 8 lbs. require from 250 to 635 watts. A substantial metal stand should always be provided and should separate the iron about $2\frac{1}{2}$ inches from cloth on board.

Flexible Cord improperly used causes the majority of electrical fires. The common cord should always hang free in air; should never be spliced, and should be soldered only where it connects to line wires. In sockets, rosettes, and outlet boxes it must be knotted to prevent strain from coming on the joints. The best method of tying knots is shown in Figure 6.

Foundries.—The general illumination of foundries is commonly effected by means of arc lamps or clusters of incandescent lamps. The flaming arc is very effective. Strong shadows are useful, as all objects soon assume the same color. Cleaning of lamps is an important item and for this reason clusters of incandescent lamps are often encased in outer globes, which are more easily cleaned. In addition to the general illumination, each molder requires an individual lamp for his own use.

Frequencies.—A frequency of 25 cycles per second is generally used for rotary converter work, and power transmission. Arc and incandescent lamps do not operate well with such low frequencies, hence a frequency of 60 cycles is generally used for illumination. In any given circuit, the higher the frequency, the greater will be the reactance. If the frequency is too high for a given device the current will be insufficient, if too low it will be excessive. A frequency changer is a machine usually installed in substations. A frequency indicator is usually installed upon switchboards, or used in connection with a large motor installation.

Fuses.—Fuses are divided into three general classes: open, enclosed, and expulsion. The fuse metal itself is never hard enough to stand up well

under binding screws, hence copper tips are necessary. If these are not used there will be much unnecessary blowing. All fuses should be placed in cabinets not only to prevent molten metal from causing fires, but to insure greater reliability of the fuse by protecting it against drafts. The fusing of branch, and main circuits inside of buildings is thoroughly covered by the National Electrical Code. The rule in general is to provide fuse protection wherever the size of wire changes. The fuse to be of such size as to prevent current rise above the safe carrying capacity of wires as given in the CODE. Each motor or other translating device also requires separate fuse protection except that small devices aggregating not more than 660 watts capacity may be grouped under one fuse.

All plans of fusing are a compromise between the desire to obtain adequate protection on the one hand, and escape the trouble caused by the many accidental breaks and uncalled for operations of fuses.

Overhead systems as a rule are not fused where they leave the switchboard, but are equipped with switches or disconnectives.

Feeders leaving the transmission lines are also usually left without fuse protection, but equipped with disconnectives.

Fuse protection is fully demanded only where the chances of short circuits or grounds are quite great, and this point is not reached until the transformers are reached. It must be borne in mind that all consumers devices are protected by service fuses and switches, and these protect the outer lines fully against everything except what occurs on the poles. The primary side of transformers of small and medium capacity is usually protected by fuses, but the fuses are made large enough so that ordinary overloads will not cause them to blow.

TABLE XXIII

The following table gives fuse sizes often used with transformers of the capacities given.

K.W. Capacity	Size Fuse Amperes	K.W. Capacity	Size Fuse Amperes
1	3	15	15
2	3	20	15
3	3	25	20
4	3	30	20
5	5	40	30
7½	10	50	40
10	10		

On the secondary side of transformers, fuses are not ordinarily used and it is not advisable to have them. In case a number of transformers feed a network the blowing of one fuse may cause the blowing of another, etc., until all are out. Under such circumstances fuses cannot well be replaced until the load on the main is sufficiently reduced to allow one transformer to carry it, or until the feeder supplying the network has been opened; in this case the feeder must be left open until all fuses have been replaced. In connection with underground circuits the case is different. Here short circuits and grounds are much more likely to occur. Such systems also always supply a much larger number of customers within a given space, and more care is necessary. Underground networks are usually fused at each junction point so that, if an overload causes one fuse to blow, the other will follow and clear the balance of the circuits from trouble. Wherever parallel lines are run they should be equipped with reverse current circuit breakers. Three phase four wire systems are usually provided with a single pole switch in each leg, thus any phase can be disconnected without interfering seriously with the others. For three phase three wire systems three pole switches are used. All telephone circuits should be protected by fuse and

in addition with "sneak coils" and air gap arresters. Heat coils are arranged to open the circuit when a small or "sneak current" has passed through them for a considerable time, or a large current in an instant. Air gap arresters are supposed to open the circuit whenever unduly high potentials come to exist at their terminals.

TABLE XXIV

Tested Fuse Wire from ½ to 100 Amperes

Safe Carrying Capacity Amperes	Best Lengths for Use and Fusing Currents for such Lengths		Length Per Lb.		Mils. Diam.
	Inches	Amperes	Ft.	In.	
½	1	1½	2550		10
¾	1	2¼	1516		13
1	1¼	3	993		16
2	1½	5	407		25
3	1½	7	265		31
4	1¾	9	207		35
5	1¾	10	167		39
6	2	12	144		42
7	2	13	120		46
8	2	15	106		49
9	2	16	94		52
10	2¼	17	84		55
12	2¼	20	68		61
14	2¼	23	58		66
15	2¼	24	55		68
16	2½	25	49		72
18	2½	28	43		77
20	2½	30	37	10	82
25	2¾	37	28	9	94
30	2¾	43	24		103
35	3	49	20		113
40	3	56	17	2	122
45	3	62	15	4	129
50	3	69	13	6	137
60	3¼	81	10	3	158
70	3¼	93	8	10	170
75	3½	99	7	9	182
80	3½	106	7	2	189
90	3½	118	5	8	212
100	4	129	5		226

Tested Fuse Strip from 50 to 600 Amperes

Safe Carrying Capacity Amperes	Best Lengths for Use and Fusing Currents for such Lengths		Weight Per Foot Ounces
	Inches	Amperes	
50	3	69	1⅛
60	3¼	81	1⅜
70	3¼	93	1¾
75	3½	99	1⅞
80	3½	106	2⅛
90	3¾	118	2½
100	4	129	3
125	4¼	158	3⅞
150	4½	187	4⅞
175	4½	215	6
200	4¾	243	6⅞
225	4¾	270	7⅞
250	4¾	298	8⅞
275	4¾	325	9¾
300	5	351	10¾
350	5¼	402	12¾
400	5¼	450	14⅝
450	5½	500	17
500	6	550	20½
600	6½	675	35

The current required to fuse metals can be found by the well known Preece formula:

$$I = a\sqrt{d^3},$$

where I = current in amperes, d = diameter of wire, and a = a constant for different kinds of metal as given below:

Copper 10244
Aluminum 7585
German Silver........5230
Iron 3148
Lead 1379

The table below is calculated from the above formula and constants, and gives the current required to fuse wires of various sizes.

TABLE XXV

B. & S.	Copper	Aluminum	German Silver	Iron	Lead
4	942	698	481	290	127
6	666	.493	339	204	90
8	471	349	240	145	63
10	334	247	171	103	50
12	235	174	120	72	32
14	165	122	84	51	22
16	117	86	60	35	16
18	82	60	42	25	11
20	58	43	29	18	8
21	49	36	25	15	6
22	40	29	21	12	5
23	36	26	19	11	5
24	29	21	15	9	4
25	25	18	13	8	3
26	20	15	11	6	3
27	17	12	9	5	2
28	14	10	7	4	2
29	12	9	6	4	1.5
30	10	8	5	3	1.2
31	8.5	6	4	2.6	1.0
32	7.0	5	4	2.2	0.9

The strands of which flexible cord is made up range from No. 26 to 36.

Galvanic.—A term much used in therapeutics to denote continuous, or direct current.

Garages.—The gasoline vapors so prevalent in garages do not ordinarily rise more than 4 feet above the floor. Avoid all possibility of electric sparks at this level, especially in pits. Electric lights should be well guarded with elastic lamp-guards which will protect the lamp against breakage even when it falls.

Gas Lighting may be effected by pilot flame, a small quantity of sponge platinum on mantle, or by high-tension electric sparks jumping a number of spark gaps in the gas jets, or low-tension sparks applied to jets in multiple. A spark coil is required and it should be connected with a tell-tale relay and bell which will ring in case the system becomes grounded. Electric gas lighting wires must not be used on same fixtures with electric light.

Gauges.—The American, or Brown & Sharp wire gauge, abbreviated respectively A. W. G. or B. & S., is the one commonly used for measuring copper, aluminum, and resistance wires in general. The U. S. steel wire gauge is commonly used for steel and iron wire. This is also known as the Washburn and Moen; Roebling, and American Steel and Wire, and is generally abbreviated Stl. W. G.

The Birmingham or Stubs' Wire Gauge is sometimes used for brass wire. It is commonly abbreviated B. W. G. This, although spoken of as Stubs, is not identical with the Stubs' Steel Wire Gauge. The British Standard Wire Gauge, the Edison Wire Gauge and the Stubs' Steel Wire Gauge are not much used in this country in electrical work. A comparison of the different wire gauges is given below, diameters being given in mils (thousandths of an inch).

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TABLE XXVI

Tabular Comparison of Wire Gauges. Diameters in Mils.

Gauge No.	American Wire Gauge (B. & S.)[22]	Steel Wire Gauge[23]	Birmingham Wire Gauge (Stubs')	Old English Wire Gauge (London)	Stubs' Steel Wire Gauge	(British) Standard Wire Gauge	Gauge No.
7-0		490.0				500.	7-0
6-0		461.5				464.	6-0
5-0		430.5				432.	5-0
4-0	460.	393.8	454.	454.		400.	4-0
3-0	410.	362.5	425.	425.		372.	3-0
2-0	365.	331.0	380.	380.		348.	2-0
0	325.	306.5	340.	340.		324.	0
1	289.	283.0	300.	300.	227.	300.	1
2	258.	262.5	284.	284.	219.	276.	2
3	229.	243.7	259.	259.	212.	252.	3
4	204.	225.3	238.	238.	207.	232.	4
5	182.	207.0	220.	220.	204.	212.	5
6	162.	192.0	203.	203.	201.	192.	6
7	144.	177.0	180.	180.	199.	176.	7
8	128.	162.0	165.	165.	197.	160.	8
9	114.	148.3	148.	148.	194.	144.	9
10	102.	135.0	134.	134.	191.	128.	10
11	91.	120.5	120.	120.	188.	116.	11
12	81.	105.5	109.	109.	185.	104.	12
13	72.	91.5	95.	95.	182.	92.	13
14	64.	80.0	83.	83.	180.	80.	14
15	57.	72.0	72.	72.	178.	72.	15
16	51.	62.5	65.	65.	175.	64.	16
17	45.	54.0	58.	58.	172.	56.	17
18	40.	47.5	49.	49.	168.	48.	18
19	36.	41.0	42.	40.	164.	40.	19
20	32.	34.8	35.	35.	161.	36.	20
21	28.5	31.7	32.	31.5	157.	32.	21
22	25.3	28.6	28.	29.5	155.	28.	22

Gauge No.	American Wire Gauge (B. & S.)[22]	Steel Wire Gauge[23]	Birmingham Wire Gauge (Stubs')	Old English Wire Gauge (London)	Stubs' Steel Wire Gauge	(British) Standard Wire Gauge	Gauge No.
23	22.6	25.8	25.	27.0	153.	24.	23
24	20.1	23.0	22.	25.0	151.	22.	24
25	17.9	20.4	20.	23.0	148.	20.	25
26	15.9	18.1	18.	20.5	146.	18.	26
27	14.2	17.3	16.	18.75	143.	16.4	27
28	12.6	16.2	14.	16.50	139.	14.8	28
29	11.3	15.0	13.	15.50	134.	13.6	29
30	10.0	14.0	12.	13.75	127.	12.4	30
31	8.9	13.2	10.	12.25	120.	11.6	31
32	8.0	12.8	9.	11.25	115.	10.8	32
33	7.1	11.8	8.	10.25	112.	10.0	33
34	6.3	10.4	7.	9.50	110.	9.2	34
35	5.6	9.5	5.	9.00	108.	8.4	35
36	5.0	9.0	4.	7.50	106.	7.6	36
37	4.5	8.5		6.50	103.	6.8	37
38	4.0	8.0		5.75	101.	6.0	38
39	3.5	7.5		5.00	99.	5.2	39
40	3.1	7.0		4.50	97.	4.8	40
41		6.6			95.	4.4	41
42		6.2			92.	4.0	42
43		6.0			88.	3.6	43
44		5.8			85.	3.2	44
45		5.5			81.	2.8	45
46		5.2			79.	2.4	46
47		5.0			77.	2.0	47
48		4.8			75.	1.6	48
49		4.6			72.	1.2	49
50		4.4			69.	1.0	50

The American Wire Gauge sizes have here been rounded off to about the usual limits of commercial accuracy.

The Steel Wire Gauge is the same gauge which has been known by the various names: "Washburn and Moen," "Roebling," "American Steel and Wire Co.'s." Its abbreviation should be written "Stl. W. G.," to distinguish it from "S. W. G.," the usual abbreviation for the (British) Standard Wire Gauge.

Generators.—*Alternating Current* generators may be of the revolving field or revolving armature type. The revolving field type is easier to insulate and less troublesome to maintain, hence is most widely used. There is another, known as an *inductor* type, in which usually all electrical parts are stationery and an iron spider is caused to revolve, it being so arranged as alternately and regularly to alter the magnetic flux and thus cause induction of e. m. f. This type is not much used.

The so-called *Induction* generator is another type, and is similar to an induction motor; in fact, an induction motor, when driven above the speed of synchronism becomes an induction generator, and delivers current to the line. This type of generator cannot operate unless other alternators provide it with the necessary exciting current. The capacity in generators for field excitation must be nearly equal to one-third of the capacity of the induction generators. This type of generator is well suited for fluctuating speeds such as are given by gas engines, but it can never constitute an entire plant. Alternating current generators are made to operate single-phase, two-phase and three-phase. The single-phase machine is not well suited for power work, and is more expensive per unit of output than polyphase machines. The two-phase generators are, as a rule, used only on old direct current installations which have been adapted to a.-c. operation. The three-phase system is the most economical and is almost universally used. It is well suited for either light or power transmission. Alternators may be built to be self-exciting, but this is not often done. Most of them require a direct current exciter.

Efficiency.—Approximate efficiencies of generators of various sizes are given about as follows: 100 K. V. A., 91 per cent; 500, 94; 1,000, 95; 2,000, 96;

3,000, 96 to 97; 5,000, 97 or better. These efficiencies vary of course with the power factor, load, voltage, etc.

Frequency.—The common frequencies are 25 and 60 cycles per second, the lower being used for transmission to substations and for power alone. The higher frequency is used for mixed lighting and power, and also for lighting alone. In a single-phase machine the current and voltage per phase have but one meaning. The power is equal to $I \times E \times$ power factor, and the product of volts and amperes gives the volt-ampere rating of the machine. In a two-phase alternator each half supplies half of the current and power. The usual four transmission wires are sometimes combined into three wires, and in such a case the voltage between the two outside wires is 1.41 times the phase voltage, and the current in the middle wire is 1.41 times the current in the outside wires. The power in such a combination may be found in two ways. Measuring current in the middle wire and the voltage across both phases, the power is equal to $I \times E \times$ power factor. Measuring current in one of the outside wires, and using phase voltage, the power is equal to $I \times E \times 2 \times$ power factor. Three-phase generators are always connected by means of 3 main wires, and sometimes a neutral, but may be either delta or star. If the delta connection is used, the phase voltage is the same as the voltage between any two wires, but the current in any phase is 1.73 times the current in any one of the wires. If the star connection is used, the voltage between any two wires is 1.73 times the voltage of any phase winding, and the current to deliver the same power will be only 0.58 of the former current in the line wires. The power with either connection is equal to $I \times E \times 1.73 \times$ power factor.

Frequencies.—The common frequencies are 60 and

25 cycles. The higher frequency is used for light, and mixed light and power loads. The lower is used for power alone and also for transmission lines to substations or converters. The frequency of any generator depends upon the speed and number of poles and may be found by the formula:

$$f = \frac{\text{r. p. m.}}{60} \times \frac{\text{number of poles}}{2}$$

The table below shows the speeds at which generators provided with a certain number of poles must operate to deliver current at the frequencies given.

TABLE XXVII

60 Cycles.

No. Poles........	4	8	12	16	20	24
R. P. M..........	1,800	900	600	450	360	300

25 Cycles.

No. Poles........	4	8	12	16	20	24
R. P. M..........	750	375	250	187½	150	125

Operation of Alternators in Parallel.—In order that alternators may be operated in parallel they must be identical in four respects. The frequency must be the same. The voltage must be the same. The current and voltages must be in phase, i.e., their maxima and minima must occur at the same instant. The wave form of the machines should be as near as possible alike.

The frequency is governed by the speed, and if it is not correct, the speed must be adjusted either by

adjusting the engine, or diameters of pulleys. The voltage can be determined by a voltmeter test.

Whether the machines are in or out of phase can be determined only by properly connected synchronizing lamps, or synchronizing instruments.

The synchronizing and keeping in step of alternators will be made easier by synchronizing the piston strokes of engines as far as possible if they are separately driven, or, if driven from a common shaft, by running one of the machines with a slack belt, which will allow it to fall in step more readily. Where synchroscopes are used the pointer will indicate which machine is running too fast or too slow: Where the synchronizing is done with lamps they may be connected so as to indicate synchronism either by darkness or light. If the machines are not in phase there will be alternations of darkness and light in the lamps which will alternate with great rapidity if the machines are much out of synchronism, but will be at longer and longer intervals as they are brought more nearly into step. The proper time to close the switch is just a moment before the period of full darkness. If the machines are nearly in synchronism when thrown together, there will be cross current which will help to bring them together, but it is best to have them synchronized perfectly before connecting.

The load cannot be divided among alternators by increasing the field excitation as with direct-current machines; it is necessary to give more steam to the engine of the light running generator. This tends to advance the generator and causes it to take more current. The power factor can be improved or altered by adjusting the field excitation. Adjust fields so that power factor of each machine is the same.

Single Machine, Operation of.—See that machine is entirely disconnected from the load. Inspect all bearings and see that they are well oiled and that oil

rings work properly. Adjust field rheostat so that all resistence is in circuit and close exciter circuit. Start machine, bringing it gradually up to speed and cutting out resistance in field rheostat until generator voltage comes to its proper value. Next throw in switches, bringing load on gradually if possible, and adjust rheostat to maintain voltage properly. Test speed to see that it is at its proper value; the speed is of greater importance with alternators than with direct current generators.

Rating.—For full details as to rating, the reader is referred to the Standardization Rules of the A. I. E. E., which are too lengthy to be given here.

The maximum, or continuous, rating of an alternator is commonly taken as the load in kilowatts it can carry at 100 per cent power factor with a maximum rise in temperature of any part of 50° C. (122° F.) above the surrounding air when that is 25° C. (77° F). Corrections for other surrounding temperatures to be made according to A. I. E. E. Standardization Rules. Another rating, used mostly in connection with street railway work, allows a temperature rise of 45° C. (113° F.) under the same conditions as above, and requires that 50 per cent more than the rated load used for two hours shall not cause a temperature rise of more than 55° C. (131° F.).

Voltage.—A voltage in excess of 12,000 or 13,000 is rarely generated direct; higher line voltages are obtained mostly by step-up transformers.

Direct Current Generators, Compound Machines.—This is a combination of shunt and series dynamo, and a distinct improvement over the shunt machine. The compound winding can be adjusted to regulate the voltage as desired. It requires the same instruments as the shunt, and in addition heavy equalizing

wires run between each pair of machines. These should be carried to the board and the main switch should be triple pole. The machine may be connected either long shunt (shunt winding bridging compound fields as well as armature), or short shunt (shunt field bridging only armature); it is merely a question of convenience. All these machines may be bi-polar or multi-polar, direct or belt connected and provided with commutating or interpoles.

Rating.—Machines are commonly rated on the basis of their continuous output in kilowatts with a maximum rise in temperature of 50° C. (122° F.) above the surrounding air at 25° C. (77° F.). For full information see A. I. E. E. Standardization Rules. The common voltages are 110 volts for lighting and small power (used mostly in isolated plants); 220 to 250 also for lighting and power, but used mostly in larger plants, and for short distance distribution; 500 to 600 volts, used almost exclusively for street railway work; 2,000 to 6,000, or more, used for series arc lighting by direct current.

The *Series Machine* is used only for constant current work. It requires the following instruments and fittings:

Short circuiting switch for fields.

Ammeter, a switchboard equipped with plugs and jacks.

A polarity indicator is often advisable.

The Shunt Machine is used for all variable current work. Its voltage regulation is poor, and requires constant attention. It requires a field rheostat, fuses, main switch or circuit breaker, volt meter, ammeter, ground detector, switchboard and pilot lamps. The voltage of this machine is variable and automatically decreases with an increase in the devices it supplies.

Greek Alphabet.—Greek letters have become the standard symbols for many quantities dealt with in

electrical and mechanical calculations. The letters and their pronunciations are given below:

Α α — Alpha.	Ι ι — Iota.	Ρ ρ — Rho.
Β β — Beta.	Κ κ — Kappa.	Σ σ — Sigma.
Γ γ — Gamma.	Λ λ — Lambda.	Τ τ — Tau.
Δ δ — Delta.	Μ μ — Mu.	Υ υ — Upsilon.
Ε ε — Epsilon.	Ν ν — Nu.	Φ φ — Phi.
Ζ ζ — Zeta.	Ξ ξ — Xi.	Χ χ — Chi.
Η η — Eta.	Ο σ — Omicron.	Ψ ψ — Psi.
Θ θ — Theta.	Π π — Pi.	Ω ω — Omega.

Gram or Gramme.—The gramme is the mass of a cubic centimeter of water at the temperature of its greatest density. It is the unit of mass and is equal to 15.43235 grains; 7,000 grains equal 1 lb. av.

Gravity Cell.—This is a cell in which copper and zinc immersed in a solution of blue vitriol are the active elements. It is used for continuous work and where small constant currents only are required.

Ground Detectors.—It is customary to provide ground detectors on all switchboards from which entirely insulated circuits are run. Tests should be made quite frequently, so as to catch a ground as soon as it comes on. When grounds exist on both sides of a system, detectors are not reliable and the part to be tested must be disconnected from the board. Continuously indicating detectors are preferable; static instruments are made which can be so used even on high voltage lines with perfect safety.

Grounding.—Any connection of any part of a current carrying conductor, or live metal part of any device which has become connected to a foreign conducting medium so as to deliver current or potential to it, is spoken of as being *grounded.* Some devices and circuits are purposely grounded, the frame or the earth being relied upon as return conductors.

The purposive grounding of wires used in connection with electrical work may be divided into two classes: The grounding of frames, conduits, etc., which are not supposed to become alive except through a breakdown of the insulation, and the grounding of wires, or devices which usually do carry current. The life and fire hazard from electrical sources may be greatly reduced by improving the insulation, so that the chance of any person or material being affected by the current is small, or by arranging a bypath which shall carry the current safely away in case live parts of the conductors come in contact with it. To provide such a shunt is the object of all grounding.

Wherever a ground connection is provided, it increases the liability of a breakdown in the insulation of the device, but at the same time reduces the possibility of serious damage from that source. Connecting the frame of any device to ground weakens the natural insulation of that device, but protects persons and property otherwise liable to injury to a considerable extent. Good cause for the grounding of live parts of electrical circuits for the purpose of protection exists only in cases where two or more voltages exist in such close proximity that there is liability of the higher voltage becoming impressed upon parts normally intended only for the lower voltage. And even under these conditions the N. E. C. authorizes the grounding only when, normally, no current is supposed to be flowing over the ground connections. The grounding of any part of a live circuit under the above conditions increases the chances of trouble but confines the trouble to that which may be possible with the lower voltage. If, for instance, the ground on the secondary of a transformer is in perfect condition, it will give positive assurance that the primary voltage cannot be impressed upon any part of the secondary system, but it will also give assurance that

any workman who may come in contact with live parts on the ungrounded side, while making a ground himself, will receive the full benefit of the secondary voltage. In general, since the grounding takes away the natural insulation, which is often relied upon to some extent but quite often does not exist at all, it will force upon manufacturers a higher standard of construction, and the net result will be increased safety in all respects except life. In order to keep the life hazard within bounds it is not customary to ground live wires operating with a potential above 250.

As a general rule, all metallic structures or pipes not normally connected to electrical sources, but liable to be accidentally so connected, should be grounded. Connection to an extensive water pipe system makes the best possible ground. Steam and hot water piping is not so reliable even if connected to water pipe systems. The steel frames of buildings are useful only with supposedly small currents confined to the same building. Gas piping is likely to cause fires if contacts work loose, or if there is any electrolytic action. Where the above means of making ground connections are not available the most economical connection is made with a galvanized iron pipe driven into the ground. The practice of one large company is to use a 1½-inch pipe 8 feet long, and drive its full length into the ground, burying the connection with it. Another company uses a ½- or ¾-inch pipe. The resistance of the ground itself is so much higher than that of the pipe that the conductivity of the larger pipe is not much better than that of the smaller, but it is more reliable for driving purposes. Where the ground is of very great importance, it is advisable to use several pipes. The pipe should enter the earth at least 6 feet, and it is probable that an additional foot or two will more than

double the usefulness in dry seasons. The resistance of the earth varies with its composition, its degree of moisture, and distance from piping, etc. Gravel and sand, because so easily drained, make very poor grounds, and rock cannot be used at all.

Overhead cables and messenger wires are provided with about one ground per mile. Ground connections may be tested with an ammeter and a voltmeter.

Connect one pole of current source to nearest hydrant or other available piping and the other to the ground. The voltage divided by the current will equal the resistance of the ground, since the piping itself may be considered as comparatively without resistance.

Hanger Boards are required for incandescent lamps indoors on series circuits, but are not necessary with arc lamps, although advisable.

Heat Coils are usually installed in connection with signaling circuits. They are arranged to open the circuit when a large current flows through them for a short time or a small current for a longer time. Their office is to guard against SNEAK CURRENTS too small to blow fuses.

Heating by Electricity.—The heating of buildings by electricity is not commercially practicable, except on a small scale, or under particularly favorable cirsumstances. It is used on a large scale only in connection with street cars. In residences, offices, factories, etc., it is used only for small spaces, or where a limited quantity of heat is required for a short time only. Since there is practically no heat wasted, no air vitiated, little space occupied, no dirt caused, the fire hazard greatly reduced and the heaters are easily portable, it compares under suitable conditions, very favorably with other means of heating. One watt hour will raise the temperature of 1 cubic foot of air about 200 degrees Fahrenheit.

The heat represented by one B. T. U. is sufficient to raise the temperature of 1 lb. of water or 55 cubic feet of air 1 degree Fahrenheit. One watt equals 3.412 B. T. U.s.

In order to heat a room properly we must first supply sufficient heat to raise the temperature the required amount; next, furnish a steady supply of heat to make up for the absorption of walls, floor and ceiling; third, heat the fresh air which must be admitted for ventilating purposes. For a rough estimate it is customary to require from one to two watts per cu. ft. in room.

The wattage necessary to raise the temperature of a room may, however, be more accurately found by the formula:

$$W = \frac{C \times t}{200} \times \frac{60}{m}$$

where W = watts
C = cubic feet of air in room
t = number of degrees F. that temperature must be raised
m = the number of minutes in which this rise must take place.

The above formula makes no allowance for radiation or ventilation.

Under average conditions it may be assumed that every square foot of wall, ceiling, and floor space will absorb heat as given in Table XXX for various temperatures. If we multiply the surfaces by the numbers given we shall obtain the rate at which watts must be supplied to maintain the temperature in a hermetically sealed room after the desired temperature has been secured.

Every human being should be provided with 3,000 cubic feet of fresh air per hour, although it is possible

to do comfortably with 2,000 feet. If the allowance per hour, however, is as low as 1,000 feet, conditions will be decidedly injurious to health and also immediately uncomfortable. Since all rooms electrically heated are small, fresh air requirements demand that the air must be changed several times per hour. In order to facilitate the calculations three tables are provided. Table XXVIII shows the number of cubic feet of air contained in rooms of various dimensions likely to be warmed with electrical heat, the height of rooms being assumed as 9 feet. This table also shows the number of square feet of radiating surface, including ceiling and floor. There is further given, in connection with each size of room, the number of times the air should be changed per hour for each occupant to afford fair ventilation. The figures given are such as it is believed the occupants will naturally provide by opening windows or doors.

In Table XXIX we have constants by which the cubic contents of rooms must be multiplied to find the number of watts necessary to raise the temperature of rooms the number of degrees given at top, in the number of minutes given at the left. To find the watts necessary to provide for air changes per hour we must multiply the cubic contents by the constants given for 60 minutes and by the number of times per hour the air is to be changed.

To find the watts lost in radiation we multiply the wall surface by the figures given in Table XXX.

Example.—A bathroom 6 by 8 feet is to be heated 20 degrees F. above the temperature of the surrounding rooms and the rise in temperature must be brought about in five minutes and then maintained for an hour afterward. What size of heater will be required? There are 432 cu. ft. in such a room and by Table XXIX for 20 degrees and five minutes we find 1.20 and multiplying this by 432 we have 518 watts re-

quired to heat the air without allowing for conduction or ventilation. From Table XXVIII we also see that there are 348 feet of surface which, multiplied by 2.5, taken from Table XXX, for twenty degrees, give us 870 watts to make up for conduction through walls. Table XXVIII further shows that the air ought to be changed five times per hour; hence, taking the constant 0.10 from Table XXIX for 60 minutes and 20 degrees and multiplying this by 5, we have 0.50, and this, multiplied by the number of cu. ft., gives us 216 watts for air changes, and this, added to 870 watts for conduction, gives us a total of 1,088 watts to keep up the temperature of our bathroom 20 degrees above that of the surrounding rooms. A 1,500-watt heater would serve such a room very nicely.

Every occupant of such a room will contribute about 125 watts of this.

With all doors and windows closed the average house is supposed to allow a change of air at least once per hour.

If a room is to be used only for a short time, a change of once per hour may thus be calculated upon. In laying out heating plants in residences where comfort of the user is the main desideratum, it is advisable to err on the side of plentiful capacity; in commercial installations where the installation is more for the benefit of workmen it may be more judicious to err in the interest of a somewhat small capacity.

In small rooms a heater should always be placed as near as possible where the cold air enters, but in large rooms, if only a portion of the room is to be heated, it should be located out of the way of drafts. The coils should be divided into proportional sections equal to 1 and 2. This will enable 1/3d, 2/3ds or the full capacity of the heater to be used as desired. Electric heating has one advantage over other forms,

and this consists in its ability to give instantaneous results, and these are best attained with heaters of comparatively large capacity, so that there will be no temptation to keep up the temperature except when it is actually needed.

TABLE XXVIII

Showing number of cu. ft.; wall surfaces (including ceiling and floor) and necessary changes of air per occupant per hour in room of dimensions given; height of ceiling 9 ft.

Width		Length in Feet. 5	6	7	8	9	10	11	12
5	Cu. feet	225	270	315	360	405	450	495	540
	Wall surface	230	258	286	314	342	370	398	426
	Air changes	9	8	7	6	5	5	4	4
6	Cu. feet	270	324	378	432	486	540	594	648
	Wall surface	258	288	318	348	378	408	438	468
	Air changes	8	6	6	5	4	4	4	3
7	Cu. feet	315	378	441	504	567	630	693	756
	Wall surface	286	318	350	382	414	446	478	510
	Air changes	7	6	5	4	4	3	3	3
8	Cu. feet	360	432	504	576	648	720	792	864
	Wall surface	314	348	382	416	450	484	518	552
	Air changes	6	5	4	4	3	3	3	3
9	Cu. feet	405	486	567	648	729	810	891	972
	Wall surface	342	378	414	450	486	522	558	594
	Air changes	5	4	4	3	3	2.5	2.2	2
10	Cu. feet	450	540	630	720	810	900	990	1,080
	Wall surface	370	408	446	484	522	560	598	636
	Air changes	4.4	4	3.2	3	2.5	2.3	2	2
11	Cu. feet	495	594	693	792	891	990	1,089	1,188
	Wall surface	398	438	478	518	558	598	638	678
	Air changes	4	3.2	3	2.6	2.2	2.0	1.9	1.7
12	Cu. feet	540	648	756	864	972	1,080	1,188	1,296
	Wall surface	426	468	510	552	594	636	678	720
	Air changes	4	3	2.6	2.3	2	2	1.8	1.7

TABLE XXIX

To find watts required to heat air in room (no allowance for radiation or changes) multiply cubic feet of air by factor in table below.

Minutes in which rise is to take place	Rise in Temperature, F. 10	15	20	25	30	35	40
5	0.60	0.90	1.20	1.50	1.80	2.10	2.40
10	0.30	0.45	0.60	0.75	0.90	1.05	1.20
15	0.20	0.30	0.40	0.50	0.60	0.70	0.80
30	0.10	0.15	0.20	0.25	0.30	0.35	0.40
45	0.07	0.10	0.14	0.17	0.20	0.23	0.27
60	0.05	0.07	0.10	0.12	0.15	0.18	0.20

TABLE XXX

To find watts needed to make up for conduction multiply wall surface by factors below.

Temperature Rise 10	15	20	25	30	35	40
1.5	2.0	2.5	3.1	3.6	4.3	5.0

To find watts necessary for ventilation, multiply watts required to heat air in 60 minutes by number of changes of air required per hour.

DOMESTIC HEATING DEVICES

(Westinghouse Electric & Mfg. Co.)

Apparatus	Watts
Broilers, 3 ht.	300 to 1,200
Chafing dishes, 3 ht.	200 to 500
Cigar lighters	75
Coffee percolators	380
Coil heaters	110 to 440
Corn poppers	300
Curling irons	15
Curling iron heaters	60

Apparatus	Watts
Double boilers for 6 in. 3 ht. stove	100 to 440
Flat irons, 3 to 8 lbs., domestic sizes	250 to 635
Foot warmers	50 to 400
Frying kettle, 8 in.	825
Frying pan	250 to 500
Griddle cake cookers, 9x12, 3 ht.	330 to 880
Griddle cake cookers, 12x18, 3 ht.	500 to 1,500
Grill	600
Heating pads	50
Instantaneous flow water heaters	2,000
Kitchenettes (complete), average	1,500
Nursery milk warmers	500
Ornamental stoves	250 to 500
Ovens	1,200 to 1,500
Plate warmers	300
Radiators	500 to 6,000
Ranges, three heats, 4 to 6 people	1,000 to 4,515
Ranges, three heats, 6 to 12 people	1,100 to 5,250
Ranges, three heats, 12 to 20 people	2,000 to 7,200
Samovar	500
Saute pans	165 to 660
Shaving mugs	150
Stoves (plain) 4 in.	50 to 220
Stoves (plain) 6 in., 3 ht.	125 to 500
Stoves (plain) 7 in., 3 ht.	120 to 600
Stoves (plain) 8 in., 3 ht.	165 to 825
Stoves (plain) 10 in., 3 ht.	275 to 1,100
Stoves (plain) 12 in., 3 ht.	325 to 1,300
Stoves, traveler's	200
Toaster stoves, 5 in. by 9 in.	500
Toasters, 9 in. by 12 in., 3 ht.	330 to 880
Toasters, 12 in. by 18 in., 3 ht.	500 to 1,500
Urns, 1 gal., 3 ht.	110 to 440
Urns, 3 gal., 3 ht.	220 to 440
Urns, 3 gal., 3 ht.	330 to 1,320
Urns, 5 gal., 3 ht.	400 to 1,700
Waffle irons, two waffles	770
Waffle irons, three waffles	1,150
Water cup	500
Water heater, bayonet type	700 to 1,500

ELECTRIC HEATING DEVICES FOR INDUSTRIAL PURPOSES

Apparatus	Watts
Annealing furnaces	200
Bar or barbers' urns, 1 to 5 gal., 3 ht.	200 to 1,700
Bakers' ovens, 30 to 80 loaves	6,000 to 10,000
Branding tool	10 to 500
Button dye heater	100
Chocolate warmers	55 to 250
Coffee urns, 1 to 20 gal.	200 to 4,000
Corset irons	350
Dental furnaces	450
Embossing head	100 to 1,000
Glue pot, ½ pt. to 25 gal.	150 to 5,000
Glue pots	110 to 880
Hat irons (small)	200
Hatters' iron, 9 to 15 pounds	450
Instrument sterilizers	350 to 500
Japanning oven	1,000 to 10,000
Laboratory apparatus flask heaters	500
Linotype pots	485
Machine irons, 2 to 18 lbs.	770
Matrix dryer	28,000
Melting pot	13,000 to 30,000
Oil tempering bath	6,000 to 20,000
Pitch kettles, 12 and 15 in. 3 ht.	300 to 1,500
Polishing irons, 3.5 to 5.5 lbs.	330 to 550
Radiators, various sizes	700 to 6,000
Sealing wax pots, .5 to 1.5 pt.	175 to 300
Shoe irons	200
Soldering irons (various sizes)	100 to 450
Soldering pots, 4 to 15 lbs. capacity	200 to 440
Tailors' iron, 12 to 25 lbs.	660 to 880
Vulcanizers for automobile tires	100 to 450

High Tension.—The N. E. C. classifies as "high potential" all voltages above 550 and below 3500, allowing a 10 per cent additional in the case of 550 volt motors. Voltages above 3500 are classed as "extra high potential." Special points to be noted with very high potentials are the Corona effect and the fact that ordinary bushings must not be used where wires enter buildings. It is best to enter wires through large open spaces.

Horsepower.—746 watts equal 1 horsepower, abbreviated H. P. One H. P. is sufficient to raise 33,000 lbs. 1 foot per minute or 1 lb. 33,000 feet per minute.

Hospitals.—In the corridors, only an indifferent illumination of about 0.5 watts per square foot is needed. Good exit and emergency lighting is usually insisted upon and as most of the inmates are helpless every possible precaution against the fire hazard should be taken. Good ventilation is also essential.

In the public wards inverted lighting or lights encased in strongly diffusing globes would give the best results. By no means should direct lighting from the ceiling be favored. A plentiful supply of outlets for heating pads, etc., will be found convenient.

In the private wards the illumination should be by means of lights placed at the head of bed and never by ceiling lights. Each lamp should be controllable by pendant switch, so as to enable patient to operate it. Separate receptacle for heating pads and other devices should be provided. In the operating rooms a very bright shadowless illumination should be provided, and this should be fitted with ample switching facilities so as to adjust it to the special needs of any operating physician. Arrange the operating lights so that no one fuse can put all of them out, or at least provide throw over switch to another set of fuses. Signaling circuits are usually also provided for all patients.

Hotels.—Exit and emergency lights should be provided in all large hotels. It is a good plan to arrange the lighting so that two circuits enter each room or apartment which contains more than one outlet. Where floors are alike this can sometimes be done by running branch circuits straight up and down, and locating all cut-outs in basement. Hall circuits should always be independent of room circuits, so as to reassure guests in case of a blowout of large fuse, or other accident which darkens a large part of the house. Door switches will be found useful for closets as well as for rooms. Vacuum cleaner circuits should be provided in all halls, close enough together to avoid the use of very long cords. In the case of hotels planned for families, a large number of outlets with which to supply lights for illumination of pictures, lamps in cozy corners, etc., will be useful. If these are not provided, the rooms will likely soon be found strung full of flexible cord, which will introduce a considerable fire risk. Special systems of wiring enabling one to turn on lights in rooms even though they be switched off there, will be very serviceable in case of fire or panic, but will add considerable to the expense. In large hotels equipped with banquet halls, carriage calls are often provided. In such halls a special outlet for moving picture arc, or stereopticon should be provided.

Hunting.—Whenever anything causes fluctuations in the speed of an alternator operating in parallel with others, it will either deliver current to the others or draw current from them. Under certain circumstances this condition may become fixed and the machines are then said to be hunting or phase swinging. This condition is liable to be most severe with machines having a large number of poles. To prevent hunting the prime mover should have a governor which is not too sensitive. The connections between the machines

should not have too much resistance, and the machines should be equipped with damping coils. To prevent excessive short circuits, reactances are sometimes cut into the external circuit. To prevent overheating, thermometers or pyrometers electrically connected are sometimes embedded in the hottest parts of machines and arranged to indicate temperatures at the outside.

Hysterisis.—This is the term which describes the lagging of the magnetism behind the magnetizing force. It causes heating of the iron and loss of energy, and is much greater with steel than with soft iron.

Illumination.—Illuminating engineering is more an art than a science, and to master it properly requires considerable experience and knowledge of many factors which can only be hinted at in a work of this kind. By means of the hints given out and the tables following, anyone, however, should be able to design a pretty satisfactory installation where ordinary commercial effects are desired. Where special effects in illumination of statuary, altars, etc., is desired, experiments with temporary lights should be made. The main requisite, where economy is not too much insisted upon, is plenty of capacity. It is never advisable to figure illumination for light colors, since colors are apt to be changed. If there is plenty of circuit capacity, a wide choice as to candle power of lamps is possible and many experiments may be made until the most satisfactory effects are obtained. In addition to the matter contained in this chapter, practical hints on the illumination of special places are given in the alphabetical order of locations referred to, and it is advisable to consult these before deciding upon any work.

The circuit capacity necessary to be installed to arrange for any degree of illumination can be deter-

mined readily by reference to Table XXXI. Multiply the floor area to be illuminated by the number of watts per square foot recommended with the various illuminants and by the foot candles desired. The result will give the number of watts for which provision should be made. Except in special cases (see *National Electrical Code Rules*) one circuit at least should be provided for each 660 watts. If large units are used, the first cost will be less, but evenness of illumination will be sacrificed unless lamps can be hung high.

The intensity of illumination obtainable from a given source varies with the height and distribution of lamps; condition, type and kind of reflectors or enclosing globes; nature and color of ceilings and walls; also with the voltage maintained, and is never quite the same at all parts of the working plane.

The figures given below are intended as approximations and for quick determination of the number of lamps required. The watts per square foot given in connection with the various illuminants are thought to be sufficient to provide an illumination of one foot candle; for greater intensities they must be multiplied by the number of foot candles desired.

Table XXXII is prepared to illustrate the difference in the quantity of wiring material required for illumination brought about by the use of large and small units or clusters of lamps. The line "Wire used per sq. ft." refers only to the wire (one leg) used between lamps. The wire needed to feed the circuits must be separately calculated. In case of arc lamps, or large incandescent lamps using one per circuit, no wire between lamps will be used. No allowance is made for switches or drops to brackets and it is assumed that circuits are run according to N. E. C. rules, never more than 660 watts per circuit. The table is not quite accurate unless the space illuminated is of such size as to allow of the use of full circuits.

TABLE XXXI

	Watts per sq. ft.				
	With proper reflectors		Indirect	frosted or inclosed	
Kind of illuminant—	Light	Dark			Color of light
Nitrogen (large units)	0.12	0.18	0.18	0.27	White
Mazda	0.20	0.30	0.30	0.45	Nearly white
Tantalum	0.31	0.46	0.46	0.69	Pale yellowish white
Gem	0.42	0.63	0.63	0.95	Pale yellowish white
Carbon	0.53	0.80	0.79	1.2	Yellowish white
Nernst	0.28	0.42	0.42	0.63	Nearly white
Mercury vapor	0.11	0.16			Bluish green
Mercury vapor, quartz tube	0.04	0.06			
Direct Current Arcs					
Open arc; series; clear globes	0.17	0.25	0.25	0.38	Nearly white
Enclosed arc; series; clear globes	0.26	0.40	0.39	0.58	Bluish white
Enclosed arc; multiple; opal inner and clear outer globes	0.36	0.54	0.54	0.81	Long arcs may be bluish white, or run into violet
Enclosed arc; multiple; opal inner and outer globes	0.42	0.63	0.63	0.95	

TABLE XXXI—Continued

Kind of illuminant	Watts per sq. ft. — With proper reflectors Light	Dark	Indirect frosted or inclosed		Color of light
Alternating Current Arcs					
Open arc; clear globes	0.23	0.35	0.34	0.51	Nearly white
Enclosed arc; multiple; opal inner and clear outer globes	0.38	0.57	0.57	0.85	Bluish white
Enclosed arc; multiple; opal inner and outer globes	0.47	0.70	0.70	1.05	Long arcs may be bluish white, or run into violet
Special Arc Lamps					
Intensified arc; opal outer globe	0.25	0.38	0.38	0.57	White
Luminous arc; series; clear globe	0.20	0.30	0.30	0.45	
Luminous arc; multiple; clear globe	0.22	0.33	0.33	0.49	White
Flaming arc; series; clear globe	0.04	0.06	0.06	0.09	White
Flaming arc; multiple; clear globe	0.05	0.07	0.07	0.10	Depends upon carbons
Regenerative flaming arc; series; opal outer globe	0.05	0.07	0.07	0.10	Yellow
Regenerative flaming arc; multiple; opal outer globe	0.07	0.10	0.10	0.15	Yellow

TABLE XXXII

The table below shows the quantity of wire (one leg) required to connect between lamps for full circuits of lamps of wattages given; not more than 660 watts on any circuit.

Wattage of Lamps	Number Per Circuit		Watts to Be Used Per Square Foot									
			.25	.50	.75	1.00	1.25	1.50	1.75	2.00	2.50	3.00
25	16	Diam. of space per lamp	10.	7.1	5.7	5.	4.5	4.	3.7	3.5	3.2	2.9
		Wire used per sq. ft...	0.09	0.14	0.18	0.20	0.23	0.25	0.27	0.29	0.32	0.35
40	16	Diam. of space per lamp	12.6	8.9	7.5	6.3	5.7	5.1	4.8	4.5	4.0	3.6
		Wire used per sq. ft...	0.08	0.11	0.14	0.16	0.18	0.20	0.21	0.23	0.25	0.28
50	13	Diam. of space per lamp	14.1	10.0	8.1	7.1	6.3	5.7	5.4	5.0	4.5	4.1
		Wire used per sq. ft...	0.07	0.10	0.13	0.14	0.16	0.18	0.19	0.20	0.22	0.24
60	11	Diam. of space per lamp	15.5	10.9	8.9	7.7	6.9	6.3	5.8	5.5	4.9	4.5
		Wire used per sq. ft...	0.06	0.09	0.11	0.13	0.15	0.16	0.17	0.19	0.21	0.22
100	6	Diam. of space per lamp	20.0	14.1	11.5	10.	8.9	8.1	7.6	7.1	6.3	5.7
		Wire used per sq. ft...	0.05	0.07	0.09	0.10	0.11	0.13	0.14	0.15	0.16	0.18
150	4	Diam. of space per lamp	24.5	17.3	14.1	12.2	10.9	10.0	9.3	8.7	7.7	7.1
		Wire used per sq. ft...	0.04	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.15
200	3	Diam. of space per lamp	28.3	20.0	16.3	14.1	12.6	11.5	10.7	10.0	8.9	8.2
		Wire used per sq. ft...	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.13
250	2	Diam. of space per lamp	31.7	22.4	18.3	15.8	14.1	12.9	11.9	11.2	10.0	9.1
		Wire used per sq. ft...	0.03	0.04	0.06	0.07	0.07	0.08	0.09	0.10	0.11	0.12

Average illumination, if made up of spots of very bright light alternating with low illumination, is no criterion of the value of illumination. The very bright spots only make the others appear less brilliant. The eye has great powers of adjustment and can get along with low illumination if it is even, but with elderly persons it cannot rapidly and often change its adjustment without causing pain and injury. The quantity of illumination should be adjustable, for not all persons can be comfortable with the same intensity. The source of light should never be visible, especially if it is of high intrinsic brilliancy. The best light is one sufficiently diffused to cast but a slight shadow. In offices, however, where one source of light must serve many persons, an absolutely shadowless inverted light is desirable. It is good practice to space outlets so that the space between lamps is from one to two times the height of lamps above the working plane. This rule requires large units for high ceilings and small ones for low places. Special reflectors, however, have a certain ratio of spacing to height which should be obtained from the maker. Buildings containing many windows require more artificial light for night work than the ordinary building.

The following tables are based on Holophane Intensive, or medium reflectors, and will give fair approximations of results to be expected from other reflectors. Holophane reflectors are of high efficiency and in some cases allowance must be made for this.

Incandescent Lamps.—These lamps are operated mostly in multiple, and when so used never at a higher voltage than 250. On series circuits the voltage used runs into the thousands, but special lamps are required. Most lamps are built marked with three voltages: top, middle, and bottom. The top voltage is preferably used; with this voltage the efficiency is the highest but the life shortened; with botton voltage

TABLE XXXIII

Table Showing Illumination in Foot Candles from 25, 40 and 60 Watt Mazda or Tungsten Lamps Arranged in One Row at Heights and Distances Apart Given in Table. Bowl Frosted Lamps Equipped with Holophane Intensive Clear High Efficiency Reflectors, Nos. 106,125, 106,130 and 106,150 Respectively.

Height of lamps in feet above plane to be illuminated.	Wattage	Distance Apart of Lamps: 3 Ft.		4 Ft.		5 Ft.		6 Ft.		7 Ft.		8 Ft.		10 Ft.		12 Ft.	
		Under lamps	Between lamps	Under lamps	Between lamps	Under lamps	Between lamps	Under lamps	Between lamps	Under l'mps	Betw'en l'mps	Under l'mps	Betw'en l'mps	Under l'mps	Betw'en l'mps	Under l'mps	Betw'en l'mps
4	25	4.22	4.16	3.18	3.2	2.7	2.4	2.4	1.9	2.2	1.5	2.1	1.1	2.0	0.6	2.0	0.4
	40	7.31	6.43	5.53	5.0	4.7	3.9	4.3	3.1	4.1	2.3	3.9	1.6	8.8	0.9	8.8	0.5
	60	11.22	10.83	8.24	8.2	7.0	6.5	6.3	5.1	5.9	3.8	5.7	2.6	5.6	1.5	5.5	0.8
5	25	3.3	3.3	2.5	2.5	2.0	2.0	1.8	1.6	1.6	1.3	1.5	1.1	1.4	0.7	1.3	0.4
	40	5.2	5.2	4.0	3.9	3.1	3.2	2.7	2.7	2.4	2.2	2.3	1.8	2.1	1.0	2.1	0.8
	60	8.9	8.7	6.7	6.6	5.3	5.4	4.6	4.4	4.2	3.6	3.9	2.8	8.7	1.6	3.6	1.0
6	25	2.7	2.7	2.1	2.1	1.7	1.7	1.4	1.4	1.2	1.2	1.1	1.0	1.0	0.7	0.9	0.5
	40	4.3	4.2	3.2	3.2	2.7	2.6	2.2	2.2	1.9	1.8	1.7	1.5	1.5	1.1	1.5	0.7
	60	7.2	7.1	5.5	5.3	4.4	4.4	3.6	3.7	3.2	3.1	2.9	2.6	2.6	1.8	2.5	1.1
7	25	2.3	2.3	1.8	1.8	1.4	1.4	1.2	1.2	1.0	1.0	0.9	0.9	0.8	0.6	0.7	0.5
	40	3.6	3.6	2.8	2.7	2.2	2.2	1.9	1.8	1.6	1.6	1.4	1.4	1.2	1.0	1.1	0.8
	60	6.1	6.0	4.7	4.7	3.8	3.7	3.1	3.1	2.7	2.7	2.4	2.3	2.1	1.7	2.0	1.2
8	25	2.0	2.0	1.6	1.5	1.2	1.3	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.6	0.6	0.4
	40	3.1	3.1	2.4	2.4	1.9	2.0	1.6	1.6	1.4	1.4	1.2	1.2	1.0	0.9	0.9	0.7
	60	5.3	5.3	4.1	4.1	3.3	3.3	2.8	2.7	2.4	2.3	2.1	2.1	1.7	1.6	1.6	1.2
10	25	1.5	1.5	1.2	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.4	0.4
	40	2.5	2.4	2.1	1.9	1.6	1.6	1.3	1.3	1.1	1.1	1.0	1.0	0.8	0.8	0.7	0.6
	60	4.2	4.0	3.2	3.2	2.6	2.6	2.2	2.2	1.9	1.9	1.6	1.6	1.3	1.3	1.1	1.1
12	25	1.2	1.2	1.0	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.4	0.4
	40	1.9	1.9	1.6	1.5	1.3	1.3	1.1	1.1	0.9	0.9	0.8	0.8	0.6	0.6	0.5	0.5
	60	3.3	3.2	2.6	2.5	2.1	2.1	1.8	1.8	1.6	1.5	1.3	1.4	1.1	1.1	0.9	0.9

TABLE XXXIV

TABLE SHOWING ILLUMINATION IN FOOT CANDLES FROM 25, 40 AND 60 WATT MAZDA OR TUNGSTEN LAMPS ARRANGED IN TWO ROWS AT HEIGHTS AND DISTANCES APART AS GIVEN IN TABLE. BOWL FROSTED LAMPS EQUIPPED WITH HOLOPHANE INTENSIVE CLEAR HIGH EFFICIENCY REFLECTORS NOS. 106,125, 106,130 AND 106,150, RESPECTIVELY.

DISTANCE APART OF LAMPS EACH WAY

Height of lamps in feet above plane illuminated.		3 Ft.		4 Ft.		5 Ft.		6 Ft.		7 Ft.		8 Ft.		10 Ft.		12 Ft.	
	Wattage	Under lamps	Between lamps	Under lamps	Between lamps	Under lamps	Between lamps	Under lamps	Between lamps	Under l'mps	Betw'en l'mps	Under l'mps	Betw'en l'mps	Under l'mps	Betw'en l'mps	Under l'mps	Betw'en l'mps
4	25	6.4	6.9	4.3	4.1	3.3	3.1	2.7	2.2	2.4	1.3	2.3	1.0	2.1	0.5	2.0	0.2
	40	10.8	11.0	7.2	6.9	5.6	4.9	4.8	3.4	4.4	1.9	4.3	1.5	3.9	0.6	3.8	0.4
	60	16.8	18.3	10.8	10.8	8.3	7.9	7.0	5.3	6.4	3.0	6.0	2.3	5.8	1.0	5.6	0.6
5	25	5.5	5.8	3.8	3.7	2.7	2.9	2.2	2.3	1.9	1.5	1.7	1.2	1.5	0.6	1.4	0.4
	40	8.8	9.1	5.9	5.9	4.2	4.7	3.3	3.7	2.8	2.2	2.8	1.7	2.2	0.8	2.1	0.5
	60	14.6	15.1	9.8	9.8	6.9	7.6	5.5	5.8	4.7	3.4	4.3	2.7	3.8	1.3	3.7	0.7
6	25	4.7	4.8	3.3	3.2	2.5	2.6	1.9	2.1	1.6	1.5	1.3	1.2	1.1	0.7	1.0	0.4
	40	7.4	7.7	5.1	5.1	3.8	4.0	2.9	3.3	2.4	2.4	2.2	1.9	1.7	1.0	1.5	0.6
	60	12.4	12.9	8.6	8.4	6.3	6.8	4.7	5.5	3.9	3.8	3.4	3.0	2.9	1.5	2.7	0.9
7	25	4.1	4.1	2.9	2.9	2.2	2.3	1.7	1.9	1.4	1.4	1 2	1.2	0.9	0.7	0.8	0.5
	40	6.5	6.7	4.7	4.4	3.4	3.6	2.7	3.0	2.1	2.3	2.0	1.9	1.4	1.1	1.2	0.7
	60	10.8	11.2	7.7	7.3	5.6	6.0	4.4	5.0	3.5	3.6	3.0	3.1	2.4	1.7	2.1	1.0
8	25	3.6	3.6	2.7	2.6	2.0	2.1	1.6	1.8	1.3	1.3	1.1	1.1	0.8	0.8	0.7	0.5
	40	5.7	5.8	4.2	4.1	3.2	3.3	2.5	2.8	1.9	2.0	1.9	1.8	1.2	1.2	1.0	0.8
	60	9.7	9.5	7.0	6.8	5.3	5.5	4.1	4.6	3.3	3.4	2.8	3.0	2.1	1.9	1 7	1.2
10	25	2.8	2.8	2.2	2.1	1.68	1.8	1.3	1.4	1.1	1.1	1.0	1.0	0.7	0.7	0.5	0.5
	40	4.5	4.6	3.6	3.3	2.7	2.7	2.1	2.3	1.8	1.8	1.6	1.6	1.1	1.1	0.8	0.8
	60	7.6	7.9	5.8	5.4	4.5	4.5	3.6	3.8	2.9	3.0	2.6	2.6	1.7	1.8	1.4	1.3
12	25	2.2	2.2	1.8	1.7	1.4	1.4	1.2	1.2	0.9	1.0	0.8	0.9	0.5	0.6	.04	0.5
	40	3.6	3.8	2.8	2.8	2.3	2.3	1.9	1.9	1.5	1.6	1.4	1.4	0.9	1.0	.07	0.8
	60	6.1	6.4	4.8	4.6	3.8	3.8	3.1	3.4	2.5	2.6	2.3	2.2	1.5	1.6	1.2	1.2

TABLE XXXV

Table Showing Illumination in Foot Candles from 25, 40 and 60 Watt Mazda or Tungsten Lamps Arranged in 3 Rows at Heights and Distances Apart Each Way as Given in Table. Bowl Frosted Lamps Equipped with Holophane Intensive Clear High Efficiency Reflectors Nos. 106,125, 106,130 and 106,150 Respectively.

Distance Apart of Lamps

Height of lamp in feet above plane to be illuminated.

Height	Wattage	3 Ft.		4 Ft.		5 Ft.		6 Ft.		7 Ft.		8 Ft.		10 Ft.		12 Ft.	
		Under lamps	Between lamps	Under lamps	Between lamps	Under lamps	Between lamps	Under lamps	Between lamps	Under l'mps	Betw'en l'mps	Under l'mps	Betw'en l'mps	Under l'mps	Betw'en l'mps	Under l'mps	Betw'en l'mps
4	25	8.6	8.1	5.4	4.6	3.9	3.4	3.1	2.4	2.6	1.4	2.4	1.1	2.1	0.5	2.1	0.3
	4	14.3	12.6	8.8	7.4	6.5	5.3	5.2	3.6	4.7	2.1	4.3	1.6	4.0	0.7	3.9	0.4
	60	22.4	20.8	13.4	11.8	9.6	8.4	7.7	5.6	6.8	3.2	6.3	2.4	5.9	1.0	5.7	0.5
5	25	7.6	7.1	5.0	4.3	3.5	3.3	2.7	2.5	2.1	1.6	1.9	1.3	1.6	0.6	1.4	0.4
	40	12.3	11.0	7.8	6.8	5.1	5.1	3.9	3.9	3.2	2.1	3.1	1.6	2.3	0.9	2.2	0.5
	60	20.3	18.0	12.5	11.1	8.4	8.2	6.4	6.2	5.3	3.6	4.7	2.8	4.0	1.4	3.8	0.7
6	25	6.6	6.2	4.5	3.9	3.2	3.0	2.4	2.4	1.9	1.6	1.5	1.4	1.2	0.7	1.0	0.4
	40	10.6	9.8	7.0	6.1	5.0	4.6	3.6	3.6	2.9	2.5	2.4	2.1	1.9	1.1	1.6	0.6
	60	17.7	16.3	11.7	9.9	8.1	7.6	5.8	6.0	4.5	4.1	3.9	3.2	3.0	1.6	2.8	0.9
7	25	5.8	5.5	4.1	3.6	3.0	2.7	2.2	2.2	1.7	1.6	1.4	1.3	1.0	0.8	0.9	0.5
	40	9.3	8.8	6.5	5.5	4.6	4.3	3.4	3.4	2.6	2.5	2.2	2.0	1.5	1.1	1.3	0.7
	60	15.6	14.6	10.7	9.0	7.5	6.9	5.6	5.5	4.3	3.9	3.5	3.3	2.6	1.8	2.3	1.1
8	25	5.2	4.9	4.0	3.3	2.8	2.6	2.1	2.1	1.7	1.5	1.4	1.3	1.0	0.8	0.8	0.5
	40	8.3	7.9	5.9	5.3	4.4	4.0	3.3	3.3	2.6	2.3	2.1	2.0	1.4	1.3	1.1	0.8
	60	14.0	12.9	9.8	8.7	7.2	6.6	5.4	5.3	4.2	3.8	3.4	3.2	2.4	2.0	1.9	1.3
10	25	4.0	4.0	3.1	2.8	2.4	2.3	1.8	1.8	1.4	1.3	1.3	1.1	0.9	0.7	0.7	0.6
	40	6.6	6.5	5.2	4.5	3.8	3.5	3.0	2.8	2.4	2.1	1.9	1.9	1.3	1.2	1.1	0.9
	60	11.1	10.9	8.3	7.3	6.3	5.7	4.9	4.6	3.8	3.5	3.1	2.9	2.1	1.9	1.6	1.4
12	25	3.2	3.2	2.6	2.4	2.0	1.9	1.7	1.6	1.3	1.2	1.1	1.0	0.8	0.7	0.6	0.5
	40	5.2	5.4	4.1	3.8	3.3	3.1	2.6	2.4	2.2	1.9	1.7	1.6	1.2	1.1	0.9	0.9
	60	8.8	9.0	6.9	6.4	5.5	5.0	4.3	4.3	3.5	3.1	2.9	2.6	2.0	1.8	1.5	1.3

TABLE SHOWING ILLUMINATION IN FOOT CANDLES FROM 25, 40 AND 60 WATT MAZDA OR TUNGSTEN LAMPS ARRANGED IN FOUR ROWS AT HEIGHTS AND DISTANCES APART EACH WAY AS GIVEN IN TABLE. BOWL FROSTED LAMPS EQUIPPED WITH HOLOPHANE INTENSIVE CLEAR HIGH EFFICIENCY REFLECTORS NOS. 106,125, 106,130 AND 106,150 RESPECTIVELY.

DISTANCE APART OF LAMPS.

Height of lamp above plane illuminated.	Wattage	3 Ft. Under lamps	3 Ft. Between lamps	4 Ft. Under lamps	4 Ft. Between lamps	5 Ft. Under lamps	5 Ft. Between lamps	6 Ft. Under lamps	6 Ft. Between lamps	7 Ft. Under l'mps	7 Ft. Betw'en l'mps	8 Ft. Under l'mps	8 Ft. Betw'en l'mps	10 Ft. Under l'mps	10 Ft. Betw'en l'mps	12 Ft. Under l'mps	12 Ft. Betw'en l'mps
4	25	9.2	9.2	5.7	5.1	4.0	3.6	3.2	2.5	2.7	1.5	2.4	1.2	2.1	0.5	2.1	0.3
	40	15.2	14.2	9.2	9.0	6.7	5.6	5.3	3.8	4.8	2.2	4.3	1.7	4.0	0.8	3.9	0.4
	60	23.6	23.2	13.9	12.8	9.9	8.9	7.9	5.8	6.9	3.4	6.3	2.6	5.9	1.1	5.7	0.6
5	25	8.4	8.4	5.4	4.9	3.7	3.6	2.8	2.7	2.2	1.7	1.9	1.4	1.6	0.7	1.4	0.4
	40	13.3	12.8	8.3	7.6	5.3	5.6	4.0	4.2	3.3	2.5	3.1	1.9	2.3	1.0	2.2	0.6
	60	21.8	20.9	13.1	12.4	8.7	8.9	6.6	6.5	5.4	3.8	4.8	3.0	4.0	1.4	3.8	0.7
6	25	7.5	7.6	4.9	4.6	3.4	3.4	2.5	2.6	2.0	1.8	1.5	1.5	1.2	0.8	1.0	0.4
	40	11.8	11.9	7.6	7.1	5.3	5.0	3.7	3.8	3.0	2.7	2.4	2.2	1.9	1.2	1.6	0.6
	60	19.6	19.6	12.6	11.5	8.5	8.4	6.0	6.4	4.6	4.3	4.0	3.3	3.0	1.7	2.8	1.0
7	25	6.7	6.8	4.5	4.4	3.2	3.1	2.3	2.5	1.8	1.7	1.4	1.4	1.0	0.8	0.9	0.5
	40	10.6	10.9	7.1	6.6	4.9	4.9	3.6	3.8	2.7	2.7	2.3	2.2	1.5	1.2	1.3	0.7
	60	17.6	18.0	11.7	10.8	8.0	7.9	5.9	6.1	4.5	4.2	3.6	3.5	2.7	1.9	2.3	1.1
8	25	6.4	6.2	4.5	4.1	3.1	3.0	2.3	2.4	1.8	1.7	1.4	1.4	1.0	0.9	0.8	0.6
	40	9.8	9.9	6.7	6.5	4.8	4.8	3.5	3.6	2.7	2.5	2.2	2.1	1.4	1.4	1.1	0.9
	60	16.3	16.3	11.0	10.6	7.9	7.7	5.7	5.9	4.4	4.2	3.5	3.5	2.5	2.1	1.9	1.3
10	25	4.9	5.1	3.7	3.6	2.7	2.8	2.0	1.4	1.5	1.5	1.4	1.3	0.9	0.8	0.7	0.6
	40	8.0	8.3	6.0	5.7	4.3	4.3	3.3	3.3	2.6	2.4	2.0	2.1	1.4	1.3	1.0	1.0
	60	13.4	14.0	9.7	9.2	7.1	7.0	5.3	5.4	4.0	4.0	3.1	3.2	2.2	2.1	1.6	1.4
12	25	4.0	4.2	3.1	3.0	2.3	2.4	1.9	1.2	1.4	1.4	1.2	1.2	0.8	0.8	0.6	0.6
	40	6.4	6.9	4.9	4.8	3.8	3.9	2.9	2.9	2.4	2.3	1.8	1.8	1.3	1.2	0.9	0.9
	60	10.9	11.6	8.3	8.2	6.3	6.3	4.8	5.2	3.8	3.7	2.9	3.0	2.1	2.0	1.5	1.4

TABLE XXXVII

TABLE SHOWING ILLUMINATION IN FOOT CANDDLES FROM 100, 150 AND 250 WATTS MAZDA LAMPS ARRANGED IN ONE ROW AT HEIGHTS AND DISTANCES APART GIVEN IN TABLE. BOWL FROSTED LAMPS EQUIPPED WITH HOLOPHANE INTENSIVE CLEAR HIGH EFFICIENCY REFLECTORS NOS. 106,180, 106,185 AND 106,190 RESPECTIVELY.

DISTANCE APART OF LAMPS IN FEET.

Height of unit above plane illuminated.	Wattage	6 Ft. Under lamps	6 Ft. Be tween lamps	8 Ft. Under lamps	8 Ft. Be- tween lamps	10 Ft. Under lamps	10 Ft. Be- tween lamps	12 Ft. Under lamps	12 Ft. Be- tween lamps	14 Ft. Un- der l'mps	14 Ft. Be- tw'en l'mps	16 Ft. Un- der l'mps	16 Ft. Be- tw'en l'mps	18 Ft. Un- der l'mps	18 Ft. Be- tw'en l'mps	20 Ft. Un- der l'mps	20 Ft. Be- tw'en l'mps
6	00	5.4	5.3	4.3	3.7	3.8	2.7	3.7	1.8	3.6	1.2	3.5	0.8	3.5	0.5	3.4	0.4
	150	9.5	9.4	7.5	6.7	6.7	4.6	6.4	3.2	6.2	2.1	6.0	1.5	6.0	1.0	6.0	0.7
	250	16	16	13	11	12	8.0	11	5.4	11	3.8	11	2.7	10	1.9	10	1.3
7	100	4.6	4.7	3.6	3.4	3.0	2.6	2.8	1.9	2.7	1.4	2.6	1.0	2.6	0.7	2.6	0.5
	150	8.0	8.2	6.2	6.0	5.3	4.4	4.9	3.2	4.7	2.4	4.5	1.7	4.5	1.3	4.4	0.9
	250	14	14	11	10	9.2	7.6	8.5	5.4	8.2	4.1	8.0	3.0	7.9	2.2	7.7	1.6
8	100	4.0	4.0	3.2	3.0	2.5	2.4	2.3	1.9	2.1	1.4	2.0	1.1	2.0	0.8	2.0	0.6
	150	7.0	7.1	5.3	5.3	4.4	4.1	4.0	3.1	3.7	2.4	3.5	1.8	3.5	1.4	3.4	1.0
	250	12	12	9.4	9.2	7.7	7.0	6.9	5.3	6.5	4.1	6.3	3.2	6.2	2.5	6.0	1.8
9	100	3.5	3.6	2.7	2.6	2.2	2.1	1.9	1.7	1.7	1.4	1.6	1.1	1.6	0.9	1.6	0.7
	150	6.2	6.3	4.6	4.7	3.8	3.7	3.4	2.9	3.1	2.3	2.9	1.9	2.8	1.5	2.7	1.1
	250	11	11	8.2	8.2	6.6	6.5	5.8	5.0	5.4	4.0	5.1	3.2	5.0	2.6	4.8	1.9
10	100	3.2	3.2	2.4	2.4	2.0	1.9	1.7	1.6	1.5	1.3	1.4	1.1	1.3	0.9	1.3	0.7
	150	5.6	5.6	4.1	4.2	3.4	3.4	3.0	2.7	2.6	2.2	2.4	1.8	2.3	1.5	2.3	1.2
	250	9.6	9.8	7.3	7.4	5.9	5.9	5.0	4.7	4.6	3.8	4.4	3.2	4.2	2.6	4.0	2.0
12	100	2.6	2.6	2.0	2.1	1.6	1.6	1.4	1.4	1.2	1.1	1.0	1.0	1.0	0.8	0.9	0.7
	150	4.5	4.6	3.4	3.5	2.7	2.8	2.4	2.3	2.1	2.0	1.8	1.7	1.7	1.5	1.7	1.2
	250	7.9	8.0	6.0	6.0	4.8	4.9	4.0	4.0	3.7	3.4	3.4	3.0	3.2	2.6	2.9	2.1
14	100	2.2	2.2	1.8	1.7	1.4	1.4	1.2	1.2	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7
	150	3.8	3.9	2.8	2.9	2.3	2.4	2.1	2.0	1.8	1.7	1.5	1.6	1.4	1.4	1.3	1.1
	250	6.6	6.8	5.1	5.0	4.0	4.1	3.4	3.4	3.1	3.0	2.8	2.7	2.6	2.4	2.3	2.0

TABLE XXXVIII

TABLE SHOWING ILLUMINATION IN FOOT CANDLES FROM 100, 150 AND 250 WATTS MAZDA LAMPS ARRANGED IN TWO ROWS AT HEIGHTS AND DISTANCES APART GIVEN IN TABLE. BOWL FROSTED LAMPS EQUIPPED WITH HOLOPHANE INTENSIVE CLEAR HIGH EFFICIENCY REFLECTORS NOS. 106,180, 106,185, AND 106,190 RESPECTIVELY.

DISTANCE APART OF LAMPS.

Height of lamps in feet above plane illuminated.	Wattage	6 Ft. Under lamps	6 Ft. Between lamps	8 Ft. Under lamps	8 Ft. Between lamps	10 Ft. Under lamps	10 Ft. Between lamps	12 Ft. Under lamps	12 Ft. Between lamps	14 Ft. Under l'mps	14 Ft. Betw'en l'mps	16 Ft. Under l'mps	16 Ft. Betw'en l'mps	18 Ft. Under l'mps	18 Ft. Betw'en l'mps	20 Ft. Under l'mps	20 Ft. Betw'en l'mps
6	100	7.03	7.88	5.01	4.66	4.19	2.46	3.95	1.84	3.69	0.76	3.59	0.60	3.52	0.34	3.49	0.30
	150	12.6	14.1	8.81	8.18	7.33	4.44	6.74	2.54	6.36	1.56	6.20	1.12	6.10	0.68	6.03	0.50
	250	21.6	24.2	15.4	14.0	12.9	7.94	11.6	4.56	11.15	2.80	10.9	1.98	10.7	1.15	10.5	0.84
7	100	6.53	7.16	4.45	4.64	3.45	2.79	3.10	1.66	2.84	0.90	2.72	0.70	2.66	0.43	2.63	0.35
	150	11.4	12.9	7.72	8.06	6.09	4.89	5.36	2.98	4.93	1.88	4.73	1.34	4.59	0.77	4.51	0.62
	250	19.6	22.3	13.7	13.7	10.6	8.52	9.28	5.24	8.57	3.32	8.30	2.40	8.07	1.40	7.82	1.04
8	100	6.01	6.60	4.14	4.32	3.00	2.95	2.55	1.86	2.29	1.10	2.16	0.86	2.07	0.47	2.04	0.39
	150	10.5	11.6	7.03	7.72	5.34	4.94	4.52	3.24	4.01	2.16	3.77	1.60	3.62	0.94	3.53	0.70
	250	18.2	20.2	12.4	13.3	9.4	9.04	7.80	5.64	6.98	3.84	6.68	2.80	6.40	1.66	6.10	1.20
9	100	5.46	6.00	3.77	4.06	2.72	2.83	2.17	1.94	1.89	1.26	1.77	0.98	1.65	0.55	1.63	0.43
	150	9.7	10.6	6.49	7.22	4.85	4.86	3.98	3.34	3.40	2.36	3.13	1.76	2.95	1.06	2.84	0.82
	250	16.8	18.3	11.5	12.5	8.47	8.54	6.85	5.80	5.95	4.12	5.59	3.10	5.27	1.87	4.92	1.40
10	100	5.12	5.48	3.52	3.82	2.62	2.72	2.04	1.96	1.71	1.40	1.52	1.08	1.42	0.64	1.39	0.52
	150	9.00	9.6	6.05	6.76	4.49	4.71	3.62	3.36	2.99	2.48	2.71	1.90	2.49	1.19	2.37	0.90
	250	15.6	16.6	9.63	11.7	7.88	8.26	6.21	5.80	5.26	4.36	4.87	3.34	4.50	2.09	4.11	1.56
12	100	4.46	4.52	3.16	3.26	2.25	2.44	1.83	1.82	1.40	1.36	1.20	1.20	1.10	0.76	1.01	0.60
	150	7.73	8.00	5.30	5.84	4.00	4.29	3 18	3.22	2.52	2.56	2.19	2.02	1.92	1.33	1.78	1.06
	250	13.5	13.8	9.35	10.2	6.98	7.56	5.39	5.52	4.43	4.44	4.01	3.48	3.55	2.36	3.07	1.84
14	100	3.86	3.88	2.83	2.92	2.11	2.14	1.65	1.68	1.31	1.32	1.11	1.20	0.93	0.82	0.87	0.74
	150	6.76	6.68	4.67	5.12	3.61	3.79	2.92	2.96	2.25	2.48	1.90	1.98	1.64	1.43	1.45	1.14
	250	11.7	11.7	8.35	8.8	6.30	6.82	4.85	5.14	3.93	4.32	3.51	3.46	3.05	2.47	2.48	1.96

the opposite will be the case. See Table XXXIX for approximate effects.

The efficiency of all lamps decreases with use. Incandescent lamps will not give good results with frequencies lower than 40; for outdoor illumination they have, however, been used with 25 cycles. The fluctuations are less noticeable with heavy filaments.

Circuit Limitations.—Not more than 660 watts are generally allowed on circuits, but where small fixture wire and fiber lined sockets and flexible cords are not used there is no serious objection to 1320 watts per circuit, or 32 lights instead of the usual 16.

Frosting.—Lamps are frosted to reduce the intrinsic brilliancy and through it become less harmful to the eye. Ordinary frosting reduces the c. p. from 5 to 10 per cent, but shortens the life from 25 to 50 per cent. Bowl frosting has no appreciable effect upon the life. The effect of coloring upon the life of the lamp is about the same as that of frosting. The effect upon the c. p. varies with the color and its density. Amber, opal and yellow absorb the least; blue, green and purple the most; blue and red are the most used colors. Not much illumination can be expected from colored lamps. In some cases lamps are merely bowl colored. The efficiency of incandescent lamps increases with the voltage, but the length of life decreases. To a certain extent, therefore, what is gained on the one hand is lost on the other.

Table XXXIX is prepared to facilitate the calculations necessary to be made in order to determine the most economical voltage at which to operate lamps. In the column "K. W. wasted" we give the K. W. wasted by the use of the middle or bottom voltage during the length of life corresponding to top voltage, which is considered the standard. In the column headed "Saving in lamp renewals" we give the percentage of lamp renewals avoided by the use of lamps

at the lower voltages. In order to find the money value of the watts wasted by any lamp we must multiply the figure given in the table by the c. p. of the lamp and the rate per K. W. In order to find how much the same combination will save us in lamp renewals we must multiply the cost of lamp by the figure in the column on "Saving in lamp renewals." If our calculation shows a net saving it will be more profitable to use the lower voltage, otherwise use the higher. Example: With energy at 5 cents per K. W. and 25 watt tungsten lamps costing 20 cents each, is it more economical to use the middle voltage than the top voltage? A 25 watt lamp gives 20 c. p. and the K. W. wasted at middle voltage is 0.050; we have therefore $20 \times 0.050 \times 0.05$, which equals 0.05, or 5 cents wasted during 1,000 hours. On the other hand, we save 0.23×0.20, which equals 0.046. The saving in cost of lamp renewals does not quite offset the loss by the lower voltage, hence the higher voltage is more economical.

In many cases such a calculation has merely an academic value. As long as the parties using the light are satisfied with that obtainable from the use of the lower voltage there is no economy in using the higher.

Smashing Point.—The useful life of a lamp is generally considered to be over when its c. p. has dropped to 80 per cent of its original value.

The following table is based on average values. The improvement in lamps is at times very rapid and in case great accuracy is required the manufacturers' guaranteed data should be obtained and used instead of values here given.

Inductance.—This is that property of an electric circuit which causes a current in it to create lines of force and thus produce a counter e. m. f. proportional to the rate of change of that current.

TABLE XXXIX

Comparative cost of illumination and lamp renewals.

Name of Lamp	Voltage Rating	Watts Per C.P.	Hours of Life	K.W. Wasted	Saving in Lamp Renewals
Mazda or	Top........	1.22	1,000	.....	....
Tungsten	Middle.....	1.27	1,300	0.050	0.23
	Bottom.....	1.33	1,700	0.110	0.41
Tungsten	Top........	In large units the type "C" or			
Gas Filled	Middle.....	gas filled lamp is fully twice as			
	Bottom.....	efficient as the common tungsten lamp but in connection with small units there is no saving, but a whiter light is obtained.			
	Top........	1.84	800	.....	....
Tantulum	Middle.....	1.91	1,075	0.056	0.26
	Bottom.....	2.00	1,350	0.128	0.41
Gem or	Top........	2.50	500	.....	....
Graphitized	Middle.....	2.65	700	0.075	0.28
Filament	Bottom.....	2.83	1,000	0.165	0.50

Less Than 50 Watts

	Top........	3.16	750	.....	....
Carbon	Middle.....	3.40	1,100	0.180	0.68
	Bottom.....	3.61	1,600	0.337	0.47

50 Watts and Over.

	Top........	2.97	650	.....	....
Carbon	Middle.....	3.18	925	0.136	0.30
	Bottom.....	3.39	1,425	0.273	0.54

TABLE XXXX

See pages 121-122. Wire tubes will take B. & S.

Shortest Length Obtainable	Longest Length Obtainable	External Diameter	Diameter of Hole	600 Volts or Less				600 to 3,500 Volts			
				Solid		Stranded		Solid		Stranded	
				S Braid	D Braid	S Braid	D Braid	S Braid	D Braid	S Braid	D Braid
½	24	36/64	20/64	10	14	12	..	..	..	..	..
½	24	44/64	24/64	8	10	8	14	14	..	14	..
1	24	52/64	32/64	3	5	4	6	6	8	8	10
1	24	60/64	40/64	0	1	2	3	2	3	2	4
1	24	$1\frac{3}{16}$	48/64	000	00	00	1	00	0	0	0
1½	24	$1\frac{7}{16}$	1	0000	0000	0000	0000	0000	000	0000	00
2½	24	$1\frac{13}{16}$	1¼			450	000				
2½	24	$2\frac{3}{16}$	1½			600	000				
2½	24	$2\frac{9}{16}$	1¾			900	000				
2½	24	$2\frac{15}{16}$	2			1,250	000				
2½	24	$3\frac{5}{16}$	2¼			1,500	000				
2½	24	$3\frac{11}{16}$	2½			2,000	000				

Three sizes in split tubes are obtainable. The inside diameters are 20/64, 24/64 and 32/64. Length is 3 inches.

TABLE XXXXI

Tables showing dimensions of porcelain insulators. See Fig. 7.

No.	Height	Over all Diam.	Diam. of Hole	Groove	Wire of Approximately Same Diam. as Groove
0	$2\frac{1}{4}$	3	$1\frac{1}{4}$	1	350,000
1	3	$2\frac{1}{8}$	$\frac{7}{16}$	$\frac{3}{4}$	0000
2	2	2	$\frac{1}{2}$	$\frac{1}{2}$	2
3	$1\frac{3}{4}$	2	$\frac{7}{16}$	$\frac{7}{16}$	4
3WG	$1\frac{3}{4}$	2	$\frac{7}{16}$	$\frac{3}{4}$	0000
$3\frac{1}{2}$	2	2	$\frac{7}{16}$	$\frac{7}{16}$	4
4	$1\frac{11}{16}$	$1\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{8}$	6
$4\frac{1}{2}$	$1\frac{7}{8}$	$1\frac{1}{2}$	$\frac{3}{8}$	$\frac{7}{16}$	4
$5\frac{1}{2}$	$1\frac{9}{16}$	1	$\frac{1}{4}$	$\frac{5}{16}$	8
6	$\frac{7}{8}$	$\frac{13}{16}$	$\frac{7}{32}$	$\frac{1}{4}$	10
7	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{1}{4}$	$\frac{7}{16}$	4
8	$\frac{15}{16}$	1	$\frac{1}{4}$	$\frac{5}{16}$	8
9	$1\frac{1}{8}$	$\frac{5}{8}$	$\frac{3}{16}$	$\frac{3}{16}$	12
10	$1\frac{3}{4}$	$1\frac{5}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	6
11	$\frac{11}{16}$	$1\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{2}$	2
12	$\frac{13}{16}$	$1\frac{3}{8}$	$\frac{5}{16}$	$\frac{9}{16}$	1
13	$\frac{3}{4}$	$\frac{15}{16}$	$\frac{1}{8}$	$\frac{5}{8}$	00
15	$1\frac{5}{16}$	$1\frac{3}{4}$	$\frac{7}{16}$	$\frac{1}{2}$	2
20	2	2	$\frac{3}{8}$	$\frac{5}{8}$	00
21	$2\frac{7}{8}$	2	$\frac{1}{2}$	$\frac{9}{16}$	1
22	$1\frac{5}{8}$	$2\frac{1}{8}$	1	$\frac{5}{16}$	350,000
23	$1\frac{1}{2}$	$1\frac{1}{2}$	$\frac{3}{8}$	1	350,000
24	$1\frac{3}{4}$	$1\frac{7}{8}$	$\frac{7}{16}$	$\frac{5}{8}$	00
25	$1\frac{1}{2}$	$2\frac{1}{2}$	$\frac{11}{16}$	$1\frac{1}{16}$	400,000
26	2	$2\frac{1}{4}$	$\frac{5}{8}$	$\frac{9}{16}$	1
29	$2\frac{3}{8}$	$2\frac{1}{2}$	$\frac{1}{2}$	$1\frac{3}{8}$	450,000
36	$1\frac{3}{4}$	$1\frac{3}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	0000
39	$1\frac{3}{4}$	$2\frac{1}{2}$	$\frac{3}{4}$	$1\frac{3}{8}$	450,000

Split knobs are made only for wires from 14 to 8.

Figure 7.—Porcelain Insulators.

TABLE XXXXII

One Wire Cleats.

Height	Width	Length	Groove	Smallest Size of Wire to Fill Out Groove B. & S.
1¼	¾	2	⅜	8
1 13/16	¾	2	⅜	8
1¾	1	2¼	½	3
2⅛	1	2¼	½	3
1¾	1⅛	2½	⅝	1
2½	1⅛	2½	⅝	1
2¼	1 3/16	2¾	¾	000
2½	1 3/16	2¾	¾	000
2⅜	1 5/16	3	15/16	250,000
2 19/32	1 5/16	3	15/16	250,000
3¼	1⅜	3⅜	1¼	6,000,000
3⅜	1 7/16	3 13/16	1⅜	750,000
3¾	1⅝	4¾	2	2,000,000
4	2	5	1⅞	1,750,000
4	2	5	1½	1,000,000

Two Wire Cleats

1⅛	⅝	3⅜	3/16	14

Three Wire Cleats

1⅛	⅝	3⅜	3/16	14

* The wire sizes given are thought to be the smallest the cleats will grip well. Diameters of wires, however, vary considerable and some single braid wires may be too small for the cleats with which they are supposed to go. See tables giving diameters of insulated wires.

Insulating Materials.—The standard insulating materials are glass, porcelain, slate (without metal veins), marble, clay and certain compositions. The general requirement is that materials to be used for

insulation shall be incombustible, shall not absorb moisture and shall not soften from heat. Wood and fiber are not approved, but are tolerated in some cases.

The dimensions and other data concerning insulators, cleats and tubes are given in Tables XXXX to XXXXII.

In buildings insulators must provide ½ inch separation between supports and wires and in damp places 1 inch is required.

Below are given sizes of bushings constructed according to the N. E. Code standard. Also the largest sizes of wire that can be used in them. The diameters of wires vary somewhat, and while it is believed that the wires given can be readily drawn through the bushings, it is advisable to use a larger bushing where it is necessary to draw wires through many of them, as in concealed knob and tube work.

Logarithms.—Logarithms are used for multiplication and division of large numbers, for raising numbers to any power or extracting roots. Every logarithm of the number 10 or greater than 10 consists of two parts—a whole number, which is known as the *characteristic,* and a decimal fraction known as the *mantissa.* The mantissa of all numbers consisting of the same digits is the same; thus in the table (which gives only the mantissa) we see that 0.8, 8, and 80 each have the same mantissa, viz., .903 09, and this mantissa would still be the same for 800 or 8000. The characteristics of these numbers, however, are not the same, but always 1 less than the number of integers or whole numbers; thus for 8 it would be 0, for 80 it would be 1, making the logarithm of 8=0.903 09 and that of 80=1.903 09. If the number of which the logarithm is to be taken is less than unity, the characteristic is 1 greater than the number of ciphers which follow the decimal point. The characteristics of various numbers are given below. The characteristic of

a number does not change unless that number be increased or decreased by one decimal place.

$$
\begin{aligned}
1\ 000\ 000 &= 6\\
100\ 000 &= 5\\
10\ 000 &= 4\\
1\ 000 &= 3\\
100 &= 2\\
10 &= 1\\
1 &= 0\\
0.1 &= 1\\
0.01 &= 2\\
0.001 &= 3\\
0.0001 &= 4
\end{aligned}
$$

The characteristics of logarithms of numbers less than 1 are treated as minus quantities and usually designated by drawing a line above them.

The characteristics serve merely to determine the location of the decimal point. Whether they are added, subtracted or multiplied, if they are positive we must add to the number (found as hereafter described) ciphers enough so that the whole number will contain one more integer than the characteristic indicates. If the characteristic is minus, we must prefix one cipher less than the characteristic indicates.

How to Find the Logarithm of a Number.—Trace along first column at the left until the first two digits of the desired number are found; next follow along the same horizontal line until the third digit is found. At this place the mantissa required will be found. Put this down, prefixing it with a decimal point, and in front of it place a number equal to one less than the number of digits composing the original number. Example: find the logarithm of 676. Tracing down the left hand column, we come to the number 67 and in this horizontal line until we come to the third number, 6, we find 829 95. As 676 contains 3 digits our

characteristic is 2 and we have 2.829 95, which is the logarithm of 676.

How to Find a Number Corresponding to a Certain Logarithm.—This is accomplished by the reverse process. Suppose we wish to find the number whose logarithm is 1.421 60; we first look for the mantissa part of it and find it in the horizontal line with 26 and under 4, giving us 264 as the required number; since the characteristic is 1 we locate our decimal point 2 places from the left and the actual number now is 26.4.

To Use Logarithms for Multiplication.—Find the logarithms of the two numbers; add them and find the number corresponding thereto. Example: What is the product of 36×88?

$$\begin{array}{r} \text{log. } 36 = 1.556\ 30 \\ \text{log. } 88 = \underline{1.944\ 48} \\ 3.500\ 78 \end{array}$$

The mantissa nearest equal to 500 78 is 499 69, which corresponds to 316. Since our characteristic is 3 we point off 4 from the left, giving us the nunber 3160.

To Divide by Logarithms.—Find the logarithms of the two numbers as before and subtract one from the other and find the number corresponding to the remainder.

To Raise a Number to Any Power.—Find the logarithm and multiply it by the index of the power. Example: What is the cube of 9?

Log $9 = .954\ 24$; this multiplied by $3 = 2.862\ 72$; looking to the table we find 862 73 as the nearest and this corresponds to 729, and as our characteristic is 2 we point off 3 from the left, which shows us that the desired number is 729.

To Extract Roots.—Find the logarithm of the number as before and divide by the index. Example: What is the cube root of 1331? The number 1331 is

not tabulated, but the mantissa of 133 will be the same and it is 123 85 with a characteristic of 3, making it 3.123 85; this divided by 3 = 1.041 28, and the number corresponding to this is 11; since our characteristic is 1 we point off 2 from the left.

The method of dealing with quantities less than unity is explained by the following example: What is the product of 0.079×0.87? The log of 0.079 is 897 63 and as there is one cipher following the decimal point our characteristic is 2; the log of 0.87 is 939 52 and as there is no cipher after the decimal point the characteristic is 1. We now add the mantissae and the characteristics separately, and as the only characteristics are minus quantities, we subtract the positive characteristic found by adding the mantissae from the sum of the negative characteristics with the net result as given below:

$$\begin{array}{ll} \bar{2} & .897\ 63 \\ \bar{1} & .939\ 52 \\ \hline \bar{3} & 1.837\ 15 \\ 1 & \\ \hline \bar{2}.837\ 15 & \end{array}$$

The nearest number in the tables to 837 15 is 836 96 and this we see corresponds to the number 688. As our characteristic is now 2 we prefix this number with one cipher, giving us 0.0688 as our product.

In case the mantissa is not tabulated and the nearest one to it is not considered accurate enough, the approximate value of the corresponding number can be found by taking the numbers corresponding to the nearest two mantissae and noting their difference. Multiply this difference by $\frac{a}{b}$ where a is the difference between the lowest mantissa and the one under con-

TABLE XXXXIII

Common Logarithms of Numbers

No.	0	1	2	3	4	5	6	7	8	9
0.		000 00	301 03	477 12	602 06	698 97	778 15	845 10	903 09	954 24
1.	000 00	041 39	079 18	113 94	146 13	176 09	204 12	230 45	255 27	278 75
2.	301 03	322 22	342 42	361 73	380 21	397 94	414 97	431 36	447 16	462 40
3.	477 12	491 36	505 15	518 51	531 48	544 07	556 30	568 20	579 78	591 06
4.	602 06	612 78	623 25	633 47	643 45	653 21	662 76	672 10	681 24	690 20
5.	698 07	707 57	716 00	724 28	732 39	740 36	748 19	755 87	763 43	770 85
6.	778 15	785 33	702 39	799 34	806 18	812 91	819 54	826 07	832 51	818 85
7.	845 10	851 26	857 33	863 32	869 23	875 06	880 81	886 49	892 09	807 63
8.	903 09	908 49	913 81	919 08	924 28	929 42	934 50	939 52	944 48	949 39
9.	952 24	959 04	963 79	968 48	973 13	977 72	982 27	986 77	991 23	995 64
10.	000 00	004 32	008 60	012 84	017 03	021 19	025 31	029 38	033 42	037 43
11.	041 39	045 32	049 22	053 08	056 90	060 70	064 46	068 19	071 88	075 55
12.	079 18	082 79	086 36	089 91	093 42	096 91	100 37	103 80	107 21	110 59
13.	113 94	117 27	120 57	123 85	127 10	130 33	133 54	136 72	139 88	143 01
14.	146 13	149 21	152 99	153 34	158 36	161 37	164 35	167 32	170 26	173 19
15.	176 09	178 97	181 84	184 69	187 52	190 33	193 12	195 90	198 66	201 40
16.	204 12	206 83	209 52	212 18	214 84	217 48	220 10	222 71	225 30	227 88
17.	230 45	232 99	235 52	238 04	240 54	243 03	245 51	247 97	250 42	252 85
18.	255 27	257 67	260 07	262 45	264 81	267 17	269 51	271 84	274 15	276 46
19.	278 75	281 03	283 30	285 55	287 80	290 03	292 25	294 46	296 66	298 85

TABLE XXXXIII—Continued

Common Logarithms of Numbers

No.	0	1	2	3	4	5	6	7	8	9
20.	301 03	303 19	305 35	307 49	309 63	311 75	313 86	315 97	318 06	320 14
21.	322 22	324 28	326 33	328 38	330 41	332 43	334 45	336 46	338 45	340 44
22.	342 42	344 39	346 35	348 30	350 24	352 18	354 10	356 02	357 93	359 83
23.	361 73	363 61	365 48	367 35	369 21	371 06	372 91	374 74	376 57	378 39
24.	380 21	382 01	383 81	385 60	387 39	389 16	390 93	392 69	394 45	396 19
25.	397 94	399 67	401 40	403 12	404 83	406 54	408 24	409 93	411 62	413 30
26.	414 97	416 64	418 30	419 95	421 60	423 24	424 88	426 51	428 13	429 75
27.	431 36	432 96	434 56	436 16	437 75	439 33	440 90	442 48	444 04	445 60
28.	447 16	448 70	450 24	451 78	453 31	454 84	456 36	457 88	459 39	460 89
29.	462 40	463 89	465 38	466 86	468 34	469 82	471 29	472 75	474 21	475 67
30.	477 12	478 56	480 00	481 44	482 87	484 30	485 72	487 13	488 55	489 95
31.	491 36	492 76	494 15	495 54	496 93	498 31	499 68	501 05	502 42	503 79
32.	505 15	506 50	507 85	509 20	510 54	511 88	513 21	514 54	515 87	517 19
33.	518 51	519 82	521 13	522 44	523 74	525 04	526 33	527 63	528 91	530 20
34.	531 48	532 75	534 02	535 29	536 55	537 81	539 07	540 33	541 57	542 82
35.	544 07	545 31	546 54	547 77	549 00	550 23	551 45	552 67	553 88	555 09
36.	556 30	557 51	558 71	559 91	561 10	562 29	563 48	564 67	565 85	567 03
37.	568 20	569 37	570 54	571 71	572 87	574 03	575 19	576 34	577 49	578 64
38.	579 78	580 92	582 06	583 20	584 33	585 46	586 59	587 71	588 83	589 95
39.	591 06	592 18	593 29	594 39	595 50	596 60	597 70	598 79	599 88	600 97

TABLE XXXXIII—Continued

Common Logarithms of Numbers

No.	0	1	2	3	4	5	6	7	8	9
40.	602 06	603 14	604 23	605 31	606 38	607 46	608 53	609 59	610 66	611 72
41.	612 78	613 84	614 90	615 95	617 00	618 05	619 09	620 14	621 18	622 21
42.	623 25	624 28	625 31	626 34	627 37	628 39	629 41	630 43	631 44	632 46
43.	633 47	634 48	635 48	636 49	637 49	638 49	639 49	640 48	641 47	642 46
44.	643 45	644 44	645 42	646 40	647 38	648 36	649 33	650 31	651 28	652 25
45.	653 21	654 18	655 14	656 10	657 06	658 01	658 96	659 92	660 87	661 81
46.	662 76	663 70	664 14	665 58	666 52	667 45	668 39	669 32	670 25	671 17
47.	672 10	673 02	673 94	674 86	675 78	676 69	677 61	678 52	679 43	680 34
48.	681 24	682 15	683 05	683 95	684 85	685 74	686 64	687 53	688 42	689 31
49.	690 20	691 08	691 97	692 85	693 73	694 61	695 48	696 36	697 23	698 10
50.	698 97	699 84	700 70	701 57	702 43	703 29	704 15	705 01	705 86	706 72
51.	707 57	708 42	709 27	710 12	710 46	711 81	712 65	713 49	714 33	715 17
52.	716 00	716 84	717 67	718 50	719 33	720 16	720 99	721 81	722 63	723 46
53.	724 28	725 09	725 91	726 73	727 54	728 35	729 16	729 97	730 78	731 59
54.	732 39	733 20	734 00	734 80	735 60	736 40	737 19	737 99	738 78	739 57
55.	740 36	741 15	741 94	742 73	743 51	744 29	745 07	745 86	746 63	747 41
56.	748 19	748 96	749 74	750 51	751 28	752 05	752 82	753 58	754 35	755 11
57.	755 87	756 64	757 40	758 15	758 91	759 67	760 42	761 18	761 93	762 68
58.	763 43	764 18	764 92	765 67	766 41	767 16	767 90	768 64	769 38	770 12
59.	770 85	771 59	772 32	773 05	773 79	774 52	775 25	775 97	776 70	777 43

TABLE XXXXIII—Continued

Common Logarithms of Numbers

No.	0	1	2	3	4	5	6	7	8	9
60.	778 15	778 87	779 60	780 32	781 04	781 76	782 47	783 19	783 90	784 62
61.	785 33	786 04	786 75	787 46	788 17	788 88	789 58	790 29	790 99	791 69
62.	792 39	793 09	793 79	794 49	795 18	795 88	796 57	797 27	797 96	798 65
63.	799 34	800 03	800 72	801 40	802 09	802 77	803 46	804 14	804 82	805 50
64.	806 18	806 86	807 54	808 21	808 89	809 56	810 23	810 90	811 58	812 24
65.	812 91	813 58	814 25	814 91	815 58	816 24	816 90	817 57	818 23	818 89
66.	819 54	820 20	820 86	821 51	822 17	822 82	823 47	824 13	824 78	825 43
67.	826 07	826 72	827 37	828 02	828 66	829 30	829 95	830 59	831 23	831 87
68.	832 51	833 15	833 78	834 42	835 06	835 69	836 32	836 96	837 59	838 22
69.	838 85	839 48	840 11	840 73	841 36	841 98	842 61	843 23	843 86	844 48
70.	845 09	845 71	846 33	846 95	847 57	848 18	848 80	849 41	850 03	850 64
71.	851 25	851 87	852 48	853 09	853 69	854 30	854 91	855 51	856 12	856 72
72.	857 33	857 93	858 53	859 13	859 73	860 33	860 93	861 53	862 13	862 72
73.	863 32	863 91	864 51	865 10	865 69	866 28	866 87	867 46	868 05	868 64
74.	869 23	869 81	870 40	870 98	871 57	872 15	872 73	873 32	873 90	874 48
75.	875 06	875 64	876 21	876 79	877 37	877 94	878 52	879 09	879 66	880 24
76.	880 81	881 38	881 95	882 52	883 09	883 66	884 22	884 79	885 36	885 92
77.	886 49	887 05	887 61	888 18	888 74	889 30	889 86	890 42	890 98	891 53
78.	892 09	842 65	893 20	893 76	894 31	894 87	895 42	895 97	896 52	897 07
79.	897 62	898 17	898 72	899 27	899 82	900 36	900 91	901 45	902 00	902 54

TABLE XXXXIII—Continued

Common Logarithms of Numbers

No.	0	1	2	3	4	5	6	7	8	9
80.	903 09	903 63	904 17	904 71	905 25	905 79	906 33	906 87	907 41	907 94
81.	908 48	909 02	909 55	910 09	910 62	911 15	911 69	912 22	912 75	913 28
82.	913 81	914 34	914 87	915 40	915 92	916 45	916 98	917 50	918 03	918 55
83.	919 07	919 60	920 12	920 64	921 16	921 68	922 21	922 72	923 24	923 76
84.	924 27	924 79	925 31	925 82	926 34	926 85	927 37	927 88	928 39	928 90
85.	929 41	929 93	930 44	930 95	931 46	931 96	932 47	932 98	933 48	933 99
86.	934 49	935 00	935 50	936 01	936 51	937 01	937 51	938 02	938 52	939 02
87.	939 51	940 01	940 51	941 01	941 51	942 00	942 50	943 00	943 49	943 98
88.	944 48	944 97	945 46	945 96	946 45	946 94	947 43	947 92	948 41	948 90
89.	949 39	949 87	950 36	950 85	951 33	951 82	952 30	952 79	953 27	953 76
90.	954 24	954 72	955 20	955 68	956 16	956 64	957 12	957 60	958 08	958 56
91.	959 04	959 51	959 99	960 47	960 94	961 42	961 89	962 36	962 84	963 31
92.	963 78	964 26	964 73	965 20	965 67	966 14	966 61	967 08	967 54	968 01
93.	968 48	968 95	969 41	969 88	970 34	970 81	971 27	971 74	972 20	972 66
94.	973 12	973 59	974 05	974 51	974 97	975 43	975 89	976 35	976 80	977 26
95.	977 72	978 18	978 63	979 09	979 54	980 00	980 45	980 91	981 36	981 81
96.	982 27	982 72	983 17	983 62	984 07	984 52	984 97	985 42	985 87	986 32
97.	986 77	987 21	987 66	988 11	988 55	989 00	989 45	989 89	990 33	990 78
98.	991 22	991 66	992 11	992 55	992 99	993 43	993 87	994 31	994 75	995 19
99.	995 63	996 07	996 51	996 94	997 38	997 82	998 25	998 69	999 13	999 56

sideration, and b the difference between the two mantissae; next add this number to the lower number. Example: Our mantissa is 2.851 60, and looking into our table, we find that it is not tabulated. The next lower is .851 26, which corresponds to the number 700; the next higher is 2.851 87, which corresponds to 710. Now, .851 60 − .851 26 leaves us 34, and the difference between 851 26 and 851 87 is 61. We have now $\frac{34}{61} \times 10$, which equals 5.57, and this added to 700 gives us the approximate value of the number corresponding to the mantissa of 2.851 60, viz., 705.57.

Magnetic Blowout.—A strong magnetic field repels an arc and is often used to break it. It is made use of in lightning arresters, and at other places where the arc is troublesome.

TABLE XXXXIV

Melting Points of Various Substances in Degrees Centigrade and Fahrenheit

	C.	F.		C.	F.
Aluminum	659	1218	Mercury	—38.7	—37.7
Antimony	630	1166	Nickel	1452	2645
Bismuth	271	520	Paraffin	52	126
Brass	900	1652	Photo emulsion	32	90
Bronze	900	1652	Platinum	1755	3191
Carbon	3600	6512	Rubber	100	212
Chronium	510	950	Silenium	218	424
Cobalt	1490	3714	Silicon	1420	2588
German Silver	1100	2012	Silver	960	1760
Glass	1300	2372	Steel, Av.	1400	2552
Gold	1063	1945	Sulphur	110	230
Gutta Percha	100	212	Tantalum	2850	5162
Iridium	2300	4140	Tin	232	449
Iron	1520	2768	Tungsten	3000	5432
Lead	327	620	Vanadium	1730	3146
Manganese	1225	2237	Wax, Bees	62	143
Marble	2500	4532	Zinc	419	787

Bureau of Standards as authority for the majority.

Mains.—This term properly used applies only to the last set of wires feeding the final distribution point. Primary mains are those which feed the individual transformers. The wires leading from transformers are usually spoken of as secondary mains, although

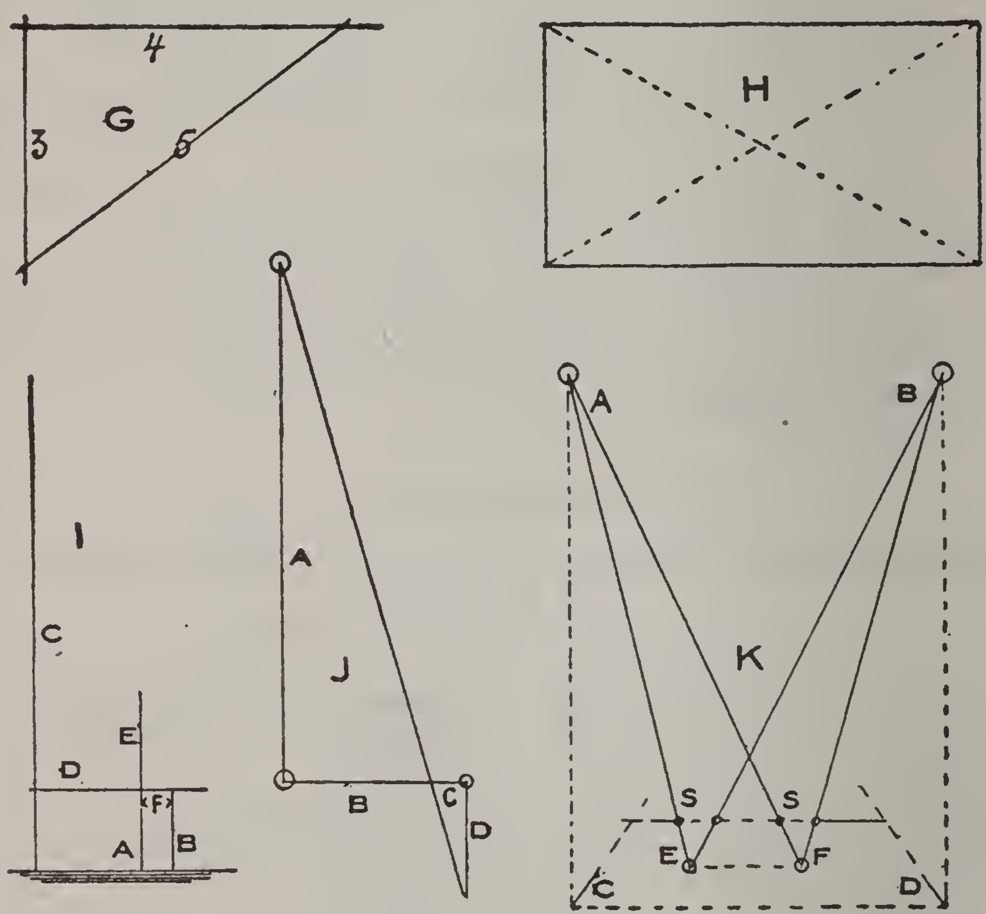


Figure 8.—Measurement of Heights and Distances.

there may be conditions in which they would be secondary feeders.

Measurement of Heights and Distances. The measurement of heights and distances requires first of all the use of right angles. Where no instruments or squares are available, a right angle can be laid out as in *G*, Figure 8, setting stakes or stretching lines so

that the dimensions given, or multiples of them, obtain on the three sides.

A square or rectangle can be proved by stretching diagonals from the corners. When both diagonals are the same length we have a perfect rectangle. See *H*, Figure 8.

The height of a pole or other object can be found by the method shown in *I*, Figure 8. Set up two stakes, *A* and *B*, a known distance apart and of a height so that their tops form a straight line with top of pole. When this is done the length of pole *C* above *D* is to *E* as *D* is to *F*, hence $C = \frac{DE}{F}$. If the total length of $D + F$ is made equal to $27\frac{1}{2}$ feet and $F = 2\frac{1}{2}$ feet, then $C = 10 \times E$. Add distance below line *D* to this to obtain total height of pole.

The distance between two points, one of which is accessible, can be found by means of the construction shown in *J*, Figure 8. Similarly to the foregoing, if *B* is made 10 times *C*, then *A* will be made 10 times *D*.

The distance between two inaccessible points may be measured by the methods shown in *K*, Figure 8. If two stakes, *C* and *D*, be set up with reference to *A* and *B*, so as to be at right angles to each other and with diagonals pointing to *A* and *B*, also forming the same angles, the distance between *C* and *D* will be equal to that between *A* and *B*.

Another method consists in setting up two stakes, *E* and *F*, and parallel to them drawing a line or laying a tape line upon the ground and setting up stakes as indicated at *S*. Measure distances between the various stakes and draw a plan of them to any convenient scale as indicated. Measure the distance between *A* and *B* on this plan. This method does not require that *E* and *F* be parallel or centered with reference to *A* and *B*.

Mensuration.—

Area of a triangle = base × $\frac{1}{2}$ altitude.
Area of a parallelogram = base × altitude.
Area of a trapezoid = altitude × $\frac{1}{2}$ the sum of parallel sides.
Area of trapezium: divide into two triangles and find area of the triangles and add together.
Area of circle = diameter^2 × 0.7854 = radius^2 × 3.1416.
Area of sector of circle = length of arc × $\frac{1}{2}$ the radius.
Area of segment of circle = area of sector of equal radius − area of triangle, when the segment is less, and + area of triangle when the segment is greater than the semi-circle.
Area of circular ring = diameters of the two circles × difference of diameters × 0.7854.
Area of an ellipse = product of the two diameters × 0.7854.
Area of a parabola = base × $\frac{2}{3}$ altitude.
Area of regular polygon = sum of its sides × perpendicular from its center to one of its sides ÷ 2.

REGULAR POLYGONS

No. of Sides		Area when dia. of inscribed circle =1	Area when side =1	Length of side when perpendicular =1	Perpendicular when side =1	Radius of circumscribed circle when side =1	Length of side when radius of circumscribed circle =1
3	Triangle	1.299	0.433	3.464	0.289	0.577	1.732
4	Square	1.000	1.000	2.000	0.500	0.707	1.414
5	Pentag.	0.908	1.720	1.453	0.688	0.851	1.176
6	Hexag.	0.866	2.598	1.155	0.866	1.000	1.000
7	Heptag.	0.843	3.634	0.963	1.039	1.152	0.868
8	Octag.	0.828	4.828	0.828	1.207	1.307	0.765
9	Nonag.	0.819	6.182	0.728	1.374	1.462	0.684
10	Decag.	0.812	7.694	0.650	1.539	1.618	0.618
11	Undecag.	0.807	9.366	0.587	1.703	1.775	0.563
12	Dodecag.	0.804	11.192	0.536	1.866	1.932	0.518

Surface of cylinder or prism = area of both ends + length × circumference.

Surface of sphere = diameter × circumference.

Convex surface of segment of sphere = height of segment × circumference of the sphere of which it is a part.

Surface of pyramid or cone = circumference of base × $\frac{1}{2}$ of the slant height + area of the base.

Surface of frustrum of cone or pyramid = sum of circumference at both ends × $\frac{1}{2}$ of slant height + area of both ends.

Contents of sphere = cube of diameter × 0.5236.

Contents of cylinder or prism = area of end × length.

Contents of segment of sphere = (height + three times the square of radius of base) × (height × 0.5236).

Contents of frustrum of cone or pyramid: Multiply areas of two ends together and extract square root. Add to this root the two areas × $\frac{1}{3}$ altitude.

Contents of a wedge = area of base × $\frac{1}{2}$ altitude.

Circumference of circle = diameter × 3.1416.

Circumference of circle = radius × 6.2832.

Circumference of circle = 3.5446 × square root of area of circle.

Circumference of circle × 0.159155 = radius.

Circumference of circle × 0.31831 = diameter.

Circumference of circle × 0.225 = side of inscribed square.

Circumference of circle × 0.282 = side of an equal square.

Half the circumference of circle × half its diameter = its area.

Square of circumference of circle × 0.7958 = area.

Diameter of circle × 0.86 = side of inscribed equilateral triangle.

Diameter of circle × 0.7071 = side of an inscribed square.

Diameter of circle × 0.8862 = side of an equal square.

Diameter = 1.1283 $\sqrt{}$square root of area of circle.
Length of arc = number of degrees × 0.017453.
Degrees in arc whose length equals radius, 57.2958°.
Length of arc of 1° = radius × 0.017453.

Meter Capacity.—It is a general rule to install meters of about one-half the capacity of the connected load in residences; three-fourths this capacity in small stores, offices, etc., and full capacity for elevator motor service and similar installations where excessive starting currents are the rule. For more exact determinations, see *Demand Factors*.

The d. c. meter is essentially a shunt motor, and its direction of rotation is independent of the polarity, but if fed from the wrong side, it will run backwards. On a. c. circuits wattmeter readings will not check with volt and ammeter reading; the latter must be multiplied by the power factor. Current transformers are used in connection with large capacity a. c. meters.

Meter Location.—Meters must always be accessible, never in places that are locked or where meter readers would cause annoyance to occupants. The location selected must be free from moisture and vibration. Meters should not be placed on curb walls of streets on which cars operate nor on thin partitions. If meters are placed in cabinets, these should be fireproofed and no magnetic material should be brought close to the meter. Meters must be set level and leveling can be accomplished by placing a small weight upon disk, and shifting meter until disk remains at rest in any position. In order that meters may be properly set, meter boards must be provided. The necessary dimensions of such boards vary with the service to be rendered and are given on Figures 9 and 10. These are the requirements in force in the City of Chicago.

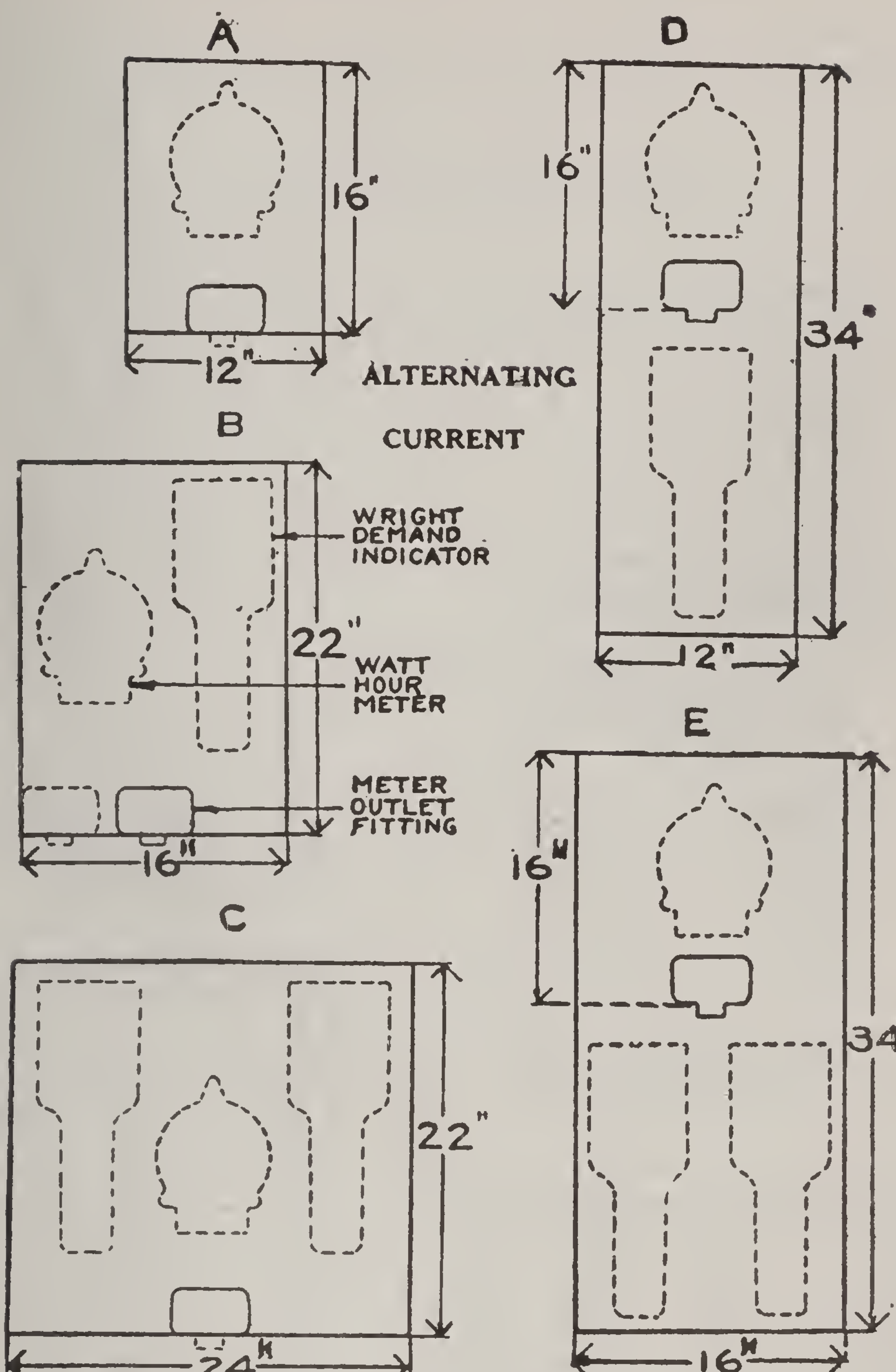


Figure 9.—Meter Fittings and Meter Boards.

Figure 9.—Showing Proper Location of Meter Fittings and Size of Meter Boards Required for Different Installations.

A. C. Residence or Apartment Lighting.

30 sockets or 1500 watts, or under, sketch *A*.

31 to 48 sockets or 1501 to 2640 watts, sketch *B* or *D*.

Above 48 sockets or 2640 watts, sketch *C* or *E*.

A. C. Business Lighting.
24 sockets or 1320 watts, or under, sketch *A*.
Above 24 sockets or 1320 watts, sketch *C* or *E*.

A. C. Power.
5 H. P., and under, single-phase, sketch *A*.
Above 5 H. P., and all three-phase, sketch *C*.

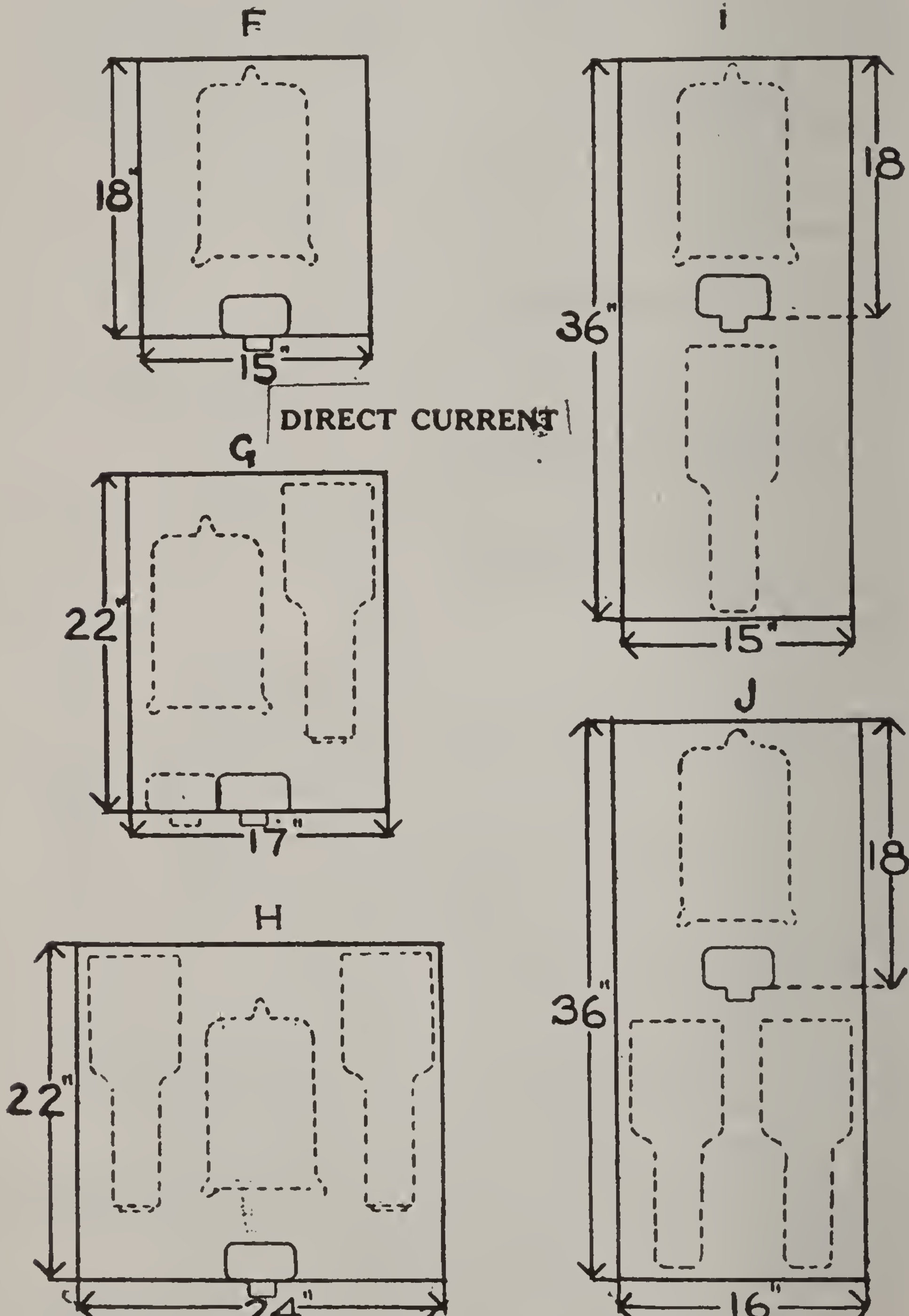


Figure 10.—Meter Fittings and Meter Boards.

Figure 10.—Showing Proper Location of Meter Fittings and Size of Meter Boards Required for Different Installations.

D. C. Residence or Apartment Lighting.
- 30 sockets or 1500 watts, or under, sketch *F*.
- 31 to 48 sockets or 1501-2640 watts, sketch *G* or *I*.
- Above 48 sockets or 2640 watts, sketch *H* or *J*.

D. C. Business Lighting.
- 24 sockets or 1320 watts, or under, sketch *F*.
- Above 24 sockets or 1320 watts, sketch *H* or *J*.

D. C. Power.
- 1500 watts, or under, sketch *F*.
- Above 1500 watts:
  - 2-wire, sketch *G* or *I*.
  - 3-wire, sketch *H* or *J*.

If the meter is located at service entrance, the measured energy will exceed the delivered energy by the percentage of loss occurring in the feed wires. If it is located at some distance from this point the service company will stand part or all of this loss.

The per cent loss per 100 feet run with different voltages, wires assumed to be loaded to full capacity, is given in Table XXXXV.

TABLE XXXXV

B. & S.	Amperes	110 v.	220 v.	440 v.	550 v.	1000 v.
14	15	4.80	2.40	1.20	0.96	0.53
12	20	5.80	2.90	1.45	1.16	0.64
10	25	4.50	2.25	1.13	0.90	0.50
8	35	4.00	2.00	1.00	0.80	0.44
6	50	3.60	1.80	0.90	0.72	0.40
5	55	3.10	1.55	0.77	0.62	0.34
4	70	3.10	1.55	0.77	0.62	0.34
3	80	2.90	1.45	0.73	0.58	0.32
2	90	2.60	1.30	0.65	0.52	0.29
1	100	2.20	1.10	0.55	0.44	0.24
0	125	2.20	1.10	0.55	0.44	0.24
00	150	2.10	1.05	0.53	0.42	0.23
000	175	1.90	0.95	0.47	0.38	0.21
0000	225	1.90	0.95	0.47	0.38	0.21
300 000	275	1.90	0.95	0.47	0.38	0.21

Reactances are not taken into consideration.

Meters, Maximum Demand.—The cost of supplying electrical energy is properly divided into two parts: One of these consists in charges to be made for meter reading, bookkeeping, and investment of capital; the other in the cost of energy consumed by the customer.

The capital investment depends largely upon the maximum demand of the customer and also upon the time at which this demand occurs. A given transformer, for instance, will serve perhaps twice as many families in which the ironing is done during the day, as it will where an iron is used at the same time with the lights. In order to obtain compensation for unnecessarily high demands for short times, maximum meters are installed, or a certain fixed charge per month is made against every customer whether current is used or not.

The maximum demand meter may be any arrangement which will indicate the highest amperage, or rate of power consumption, during any month or other convenient term. The method of computing bills where these meters are installed is somewhat confusing to one who does not make a business of it, and to show the influence of max. meters the following table is presented: This table shows the average rate per K. W. hour brought about by different maximum demands and total K. W. consumption per month.

TABLE XXXXVI

Max. Amp.	Total K.W. Hours							
	25	50	75	100	125	150	200	300
25	11.	11.	11.	10.1	9.3	8.7	7.7	6.4
20	11.	11.	10.4	9.3	8.6	8.0	7.0	6.0
15	11.	11.	9.3	8.4	7.9	6.9	6.2	5.5
10	11.	9.3	8.	7.	6.4	6.	5.5	5.
5	9.3	7.	6.	5.5	5.2	5.	4.7	4.4

This table is based on a charge of 11 cents per K. W. hour for the first thirty hours of the maximum used; 6 cents per K. W. hour for the next thirty hours of the maximum, and 4 cents per hour for the balance. The maximum load is found by multiplying the highest amperage during the month by the volts. If we have a maximum of 10 amperes our first charge will be $10 \times 110 \times 30 \times 0.11 = \$3.63$; the next will be $10 \times 110 \times 30 \times 0.06 = \$1.98$, and for the remaining K. W. hours we charge 4 cents, which equals $1.60, giving us

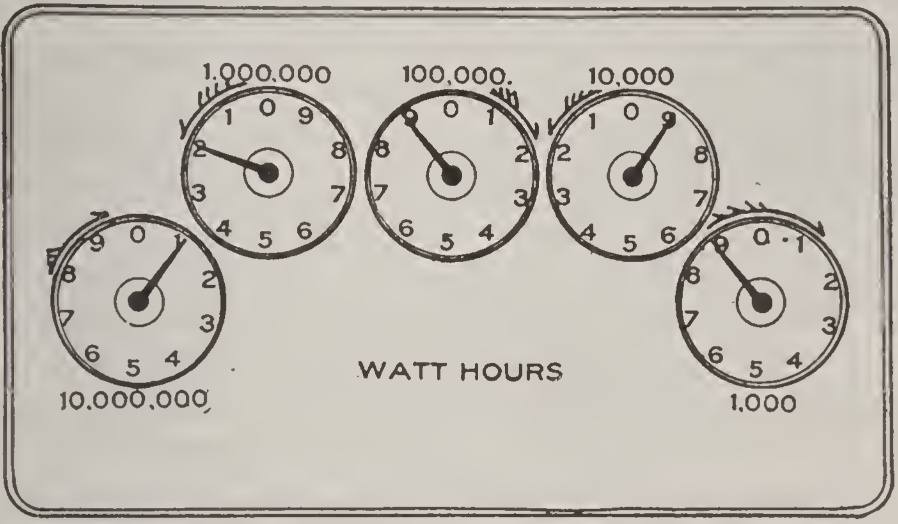


Figure 11.—Meter Dials.

a total of $7.21 for the 100 K. W. hours used, or approximately 7 cents per K. W. In the table the change in rates per K. W. is shown as affected by the proportion between the maximum demand and the total consumption.

Meter Reading.—This is a very simple matter when one has become accustomed to it, but is very confusing to those who have not had it to do. Most meters have five dials arranged somewhat on the order shown in Figure 11. These dials are all connected by gearing and serve merely as counters. The one at the right is driven by the meter mechanism proper, and through it the others are driven in turn. In the

whole train each one revolves in a direction opposite to that of the one driving it, as indicated by arrows and also by the numbers used. The proportion of the gearing is such that while the pointer on the driving dial makes one complete revolution, the one on the next dial to the left makes only one-tenth of one revolution. From this it follows that any pointer, except the one at the extreme right, can be fully on any number only at the same time that the pointer to the right of it is on 0. This is the principal point to bear in mind in meter reading. In Figure 11 a complete revolution of any pointer indicates the use of the number of watt hours found at the top of that dial. Meter reading is best begun by noting the reading of the dials from right to left, although persons who have become accustomed to it find no trouble in reading from left to right. Let us begin reading our meter from right to left and note this rule: Put down the indication of the right-hand dial, and unless its pointer is fully on, or has just passed, 0, choose the lowest of the two numbers between which the pointer may be on the next dial, and continue in this manner, putting down each number to the left of the last. Following out this rule we have first 900, next 8, then another 8, after that 1, and for the fifth dial another 1, giving us a total of 1 188 900 watt hours. Striking out 3 figures at the right reduces this to K. W. hours. It must be borne in mind that some meters are arranged to read directly in K. W. hours and some require the use of multipliers to determine the actual watts registered.

Meter Testing.—In large cities meter fittings are usually provided for the connection of meters and the best of these are arranged to allow of easy connection for meter without interfering with the operation of meters. On all meters the disk is arranged to make a certain number of revolutions per K. W. and

if this is known the load on the meter at any moment can be determined. The relation between the number of revolutions of the disk and the corresponding dial reading may be expressed by a multiplier which is known as the "constant" of the meter and is usually marked upon the disk or somewhere near it. The value of this constant in any particular instrument depends entirely upon the gearing between the disk and dial. Meter constants may be expressed in the following ways (1) number of watt hours indicated by one revolution of the disk; (2) the number of watt seconds indicated by one revolution of the disk; (3) the speed in R. P. M. at full load or rated load.

If K stands for the constant of the meter in either of the meanings given above and R for the number of revolutions made in S seconds, the load passing through the meter during any interval of time will be found by the following formulae:

$$1.\ \text{Watts} = \frac{KR \times 3600}{S}$$

$$2.\ \text{Watts} = \frac{KR}{S}$$

$$3.\ \text{Watts} = \frac{KR}{S}$$

The testing of meters is best done by connecting a standard meter in series with it, and comparing the readings. The test meter may be connected so as to measure the operating current in addition to the load of the one under test. In this case the meter under test will be found "slow" if it is arranged to measure that current; if the test meter is connected to avoid this current the other will be found "fast." Before making any test the meters should be allowed to be in circuit for about 15 minutes. A stop watch must be used if accurate results are required. On important

installations it is advisable to test meters at least twice per year. In some cases two meters are installed in parallel; such meters are a constant check upon one another.

Motion Pictures.—*Photography.*—Cooper Hewitt lamps are used almost exclusively for this purpose, and about 50,000 c. p. are required to do good work. Lamps must be arranged adjustable to suit whim of producer.

Exhibition.—The exhibition of motion pictures may be carried on with one arc lamp, but it should have an adjustable rheostat or compensator. Many films are very dark, and require extra strong lighting. Good exhibitions require at least two machines and a corresponding number of arc lamps, one to be ready when the other runs out. Stereopticon lamps and spot lights must also often be provided for. It is customary to require at least a No. 6 wire for each motion picture arc, as they often draw as high as 50 amperes. There is considerable fire and life hazard connected with the exhibition of motion pictures, and each municipality usually has some rules governing the handling of films and apparatus, which should be consulted.

Motors.—*Alternating Current.*—There are four general types of alternating current motors; viz., induction, series, repulsion and synchronous motors.

Induction Motors.—The stationary part of this motor is termed the "stator," the moving part the "rotor." That part of the winding which receives current from the supply line is known as the "primary," the other as the "secondary." From a mechanical point of view this is the simplest and best of all motors, and it is also the most used type. Polyphase induction motors are self-starting, but singlephase motors require some special starting device. These motors are essentially constant speed motors,

but their operation depends upon the "slip," which requires a slight reduction of speed with increasing load. This motor has a poor starting torque and often requires four or five times the running current to start it.

The rotor of the common induction motor is not provided with any winding, but for special purposes, such as printing presses, cranes, etc., wound rotors are often used. Resistances can be used with such motors and the speed also thus controlled. The speed will, however, be variable with the load and the motor will require watching. With a wound armature the torque is the same for all speeds. Auto-starters, or compensators, are used to start the larger motors, but the smaller ones may be connected directly to the circuit. A throw over switch fused on one side only, and so connected that the starting current need not pass through the fuses, is generally used for medium size motors, up to 5 H. P.

The synchronous speed of an induction motor can be found by the formula:

$$\text{R. P. M.} = \frac{60 \times \text{frequency}}{\text{number of pairs of poles}}$$

Below is a tabulation of all possible speeds of synchronism of 60 and 25 cycle motors with the numbers of poles given:

Number Poles	60 Cycles	25 Cycles
2	3600	1500
4	1800	750
6	1200	500
8	900	375
12	600	250
16	450	187½
24	300	125

Actual speeds, on account of "slip," are from 3 to 10 per cent lower.

Repulsion Motor.—The field winding of this motor is similar to that of a single-phase induction motor. There is no connection whatever between it and the armature, and the latter is always wound and provided with a commutator and short-circuiting brushes. The currents induced in the armature always tend to oppose those in the field, hence the name, repulsion motor. The speed of this motor is variable with the load and may be above synchronism, but the operation at this speed is not satisfactory. In some types the direction of rotation, speed, regulation, and stopping and starting may all be accomplished by simply shifting the brushes. Some single-phase motors are arranged to start as induction repulsion motors. When the motor is up to speed, the brushes are automatically thrown off, and the motor continues to run as a simple induction motor. The starting current of this type of motor is from two to three times the full load current and the starting torque is good.

Reversing Direction of Rotation.—The synchronous motor is not self-starting, and will run in whichever direction it is started. It is usually started by a small induction motor, and to reverse its direction of rotation the connections of the latter must be changed. Polyphase synchronous motors may be started by turning on the a. c. current while the d. c. fields are open. In such a case the direction of rotation can be changed by reversing two-phase wires in the same manner that induction motors are reversed. To reverse the direction of rotation of a two-phase motor, the two wires of one phase must be changed. If there are only three wires the connections must be changed so that the relative direction of current through one of the phases is reversed.

Three-phase induction motors are reversed by changing the connections of any two-phase wires. The direction of rotation of a single-phase induction

motor is indeterminate unless it is provided with some special starting apparatus. Some may be started by hand and will run in whichever direction they are started; others require that the connections of the starting coils (not starting box) be reversed. The alternating current series motor may be reversed in the same manner as d. c. motors. The repulsion motor may be reversed by either shifting the brushes or reversing the field connections.

Series Motor.—This type of alternating current motor has about the same general characteristic as the direct current series motor. Except in small sizes it cannot be used without constant attendance. The field magnets are always laminated and the fields must be obtained with as few turns of winding as possible, as the self-induction increases as the square of the number of turns of wire. Series motors may be had for use either on alternating or direct current circuits.

The armature is relatively more powerful than the fields, and the field distortion is therefore greater than in direct current series motors. To regulate this, many of the motors are provided with extra coils, some of which are in series with the fields and armatures, and others arranged to receive current only by induction.

Synchronous Motors.—These motors may be either single of polyphase. They must run at an absolutely constant speed governed by that of the generator. This speed may be found by the formula

$$\text{R. P. M.} = \frac{60 \times \text{frequency}}{\text{number of pairs of poles}}$$

All synchronous motors require direct current for field excitation. They are not self-starting in the true sense of the word, and must be brought up to nearly the proper speed before current is finally turned on.

Synchronous motors are not much used, but where they are used they may be made to exert a beneficial effect upon the power factor of the line. They cannot be made to start under load, and if overloaded will come to a stop. "Hunting" or "phase swinging" is one of the chief troubles encountered with synchronous motors. The two chief objections to synchronous motors are: they require direct current for field excitation, and skilled attendance for starting.

Starting of a. c. Motors.—Most synchronous motors are started by small induction motors and gradually brought up to the speed of synchronism. A synchroscope is usually provided to determine when the proper moment to throw in switch has arrived.

Polyphase synchronous motors may be made self-starting by opening the field circuit and allowing the line currents to pass through the armature. The armature then creates its own fields, and begins to revolve on the principle of an induction motor. The speed gradually increases, and when it reaches about that of synchronism, the d. c. field circuit is closed. Where motors are started in this way, an ammeter should be in the circuit and the current observed. If the current grows less after the field circuit is closed, the motor is working properly; if otherwise, the switch must be opened again, and a new trial made. This method of starting should not be used unless it is known that the motor is arranged for it. Very high potentials may be induced and break down the insulation.

The starting current of induction motors thrown directly onto the line is from three to ten times the normal running current, and to keep it from becoming excessive, compensators or auto-transformers are usually inserted in the line wires. This provides low voltage for starting. There are usually either three or four taps in the connections of an auto-transformer. When only three are provided it is customary to

arrange them to give 50, 65, and 80 per cent of the line voltage. Four taps are used only with the largest motors and in such a case the taps are arranged for about 40, 58, 70, and 80 per cent of the line voltage. Always make the connection for the lowest voltage at which the motor can be started. Modern starters are equipped with no-voltage and overload releases.

Three phase motors may be connected either in star or delta. If the latter is the permanent connection the switching arrangement may be such as to put the motor in star for starting, the switch being thrown over when the motor has attained some speed. In cases where the three transformers are near the motor the transformer connections may be switched in the same way, using the star connection to start the motor and throwing over to delta when it has gained some in speed.

Medium sized motors are often connected direct to the line without any means of reducing the voltage. In such cases a throw-over switch unfused on one side, but properly fused on the other, is provided. The switch is closed on the unfused side until the motor has attained its speed and is then thrown over to bring it under the protection of the fuses. With this arrangement the fuses at motor may be provided to fit the running current while those at the beginning of supply line must be large enough to stand the starting current which is often very excessive.

Speed Control.—The speed of a synchronous motor is unchangeable and governed entirely by the frequency and number of poles. The speed of an induction motor varies directly as the frequency, and if we have means of changing this, we may obtain any speed desired.

The same formula for speed which shows the above, also shows that the speed can be varied by varying the

number of poles. This is sometimes accomplished by switching devices which combine poles so as to reduce their number by one-half. This method is not much used.

The speed can also be altered by changing the voltage applied to the motor. A fourth method of speed control consists in providing a wound armature in place of the ordinary squirrel cage armature and placing resistances in the armature windings. Sometimes these resistances are located inside of the armature spider, at other times the leads are brought out, and the resistances mounted outside of the machine. The loss in speed of an induction motor with increasing load is proportional to the resistance in the rotor circuit, and if carried too far will cause the motor to stop. A reduction in speed of from 15 to 20 per cent will cause the ordinary squirrel cage motor to stop, but with a wound rotor the variation may be much greater. The speed control of a.c. motors is never very satisfactory, but where it must be, the wound rotor method is the most practical.

Variable Speed Arrangements of Motors.—A well known method of obtaining various speeds is that known as the "tandem," "cascade" or concatenation method of coupling two motors together to obtain variable speed. The first motor is fed direct from the line through suitable starters and the currents in the second motor are produced in the wound rotor of the first. The rotor of the second motor is also wound and equipped with controlling resistances. Four speeds are obtainable. First, the natural speed of motor 1 running alone; second, that of motor 2 running alone; third, the speed of the two motors combined when both tend to revolve in the same direction, and fourth, the speed of the two motors combined when one tends to run in the opposite direction.

Connected in direct concatenation (both motors

tending to run in the same direction) the speed can be found by the formula

$$\text{R. P. M.} = \frac{60 \times \text{frequency}}{\text{number of pairs of poles on both machines}}$$

When one of the rotors is connected to oppose the other the speed is

$$\text{R. P. M.} = \frac{60 \times \text{frequency}}{\text{difference in number of poles in the two machines}}$$

If the number of poles on the two machines is the same, they will run at half speed when connected in direct concatenation.

This method of control is not of much use with frequencies above 25 cycles on account of a low power factor. With this method a wound rotor is also always employed.

Motor Testing.—Motors may be tested to determine their capacity in H. P. or K. W.; their insulation resistance; their heating; speed regulation, and efficiency.

The H. P. capacity of a motor, other things being equal, depends entirely upon the current which the armature will stand, and this, assuming proper mechanical construction, depends entirely upon the heating. The heat generated is proportional to the square of the current, but the temperature of the wire is influenced considerably by the ventilation. The temperature also depends upon the length of time the current is used, and therefore the actual H. P. which any motor may develop depends very much upon whether it is to be used continuously or intermittently. Every motor thus has two ratings.

The continuous rating of a motor is at present usually taken as the output in H. P., or K. W. which it can deliver continuously, with a maximum rise in

temperature above the surrounding air at 25° C. (77° F.) of not more than 40° C. (104° F.) on field and armature, and not more than 55° C. (131° F.) on commutator. The intermittent rating differs from this in that it allows a temperature rise of 65° C. on field and armature and 90° on the commutator to be attained in an hour's run. Motors designed to fulfill these requirements can be given a still higher overload rating to be used in connection with apparatus which is in operation for only a few minutes at a time. The test for heating is made by a thermometer placed upon the parts and covered with waste to shut out the cooling influence of the air. The places of highest temperature should be selected.

The H. P. output of a motor may be found by the well-known prony brake test. To make the test, adjust the screws until the motor speed is reduced sufficiently to allow the desired current through the armature. The H. P. of the motor can then be found by the formula:

$$\text{H. P.} = \frac{s \times l \times p}{33{,}000}$$

where s = speed of pulley; l = length of lever from center of pulley to scale attachment, and p = the pull on scales in pounds.

The H. P. delivered to the motor is equal to the product of volts and amperes, and dividing the H. P. developed by the motor by that delivered to it, will give us the efficiency. The prony brake test cannot well be continued long enough to test heating of motor, and some other form of load must be placed upon it. The speed regulation of a motor may be found by operating the motor at various loads from zero to maximum, and noting the changes in speed. In testing alternating current motors we must multiply the product of volts and amperes by the power

factor, or use a wattmeter instead of volt and ammeters. The starting torque of a motor can be found in the same way as we found the H.P., but we must adjust the screws until the armature comes to a standstill.

Motor Troubles.—*If the fuses blow at starting,* contacts may be loose or dirty, or the fuses are of insufficient capacity. The motor may be overloaded or out of order in some way. The brushes may not be properly set. The rheostat may be manipulated too fast. It is usual to allow about 30 seconds to pass during the starting of the ordinary motor. The supply voltage may be higher than the motor is intended for, or the rheostat may be too large, and not introduce sufficient resistance. The motor may be improperly connected. The field circuit may be open. This would prevent the armature from generating the necessary counter e.m.f. There may be a short circuit in the armature, or in the fields. If a short circuit cuts out part of the field, it will indicate itself by undue heating and prevent the armature from picking up. If the frequency is too low, there will be an excessive current; if it is too high, there will be insufficient current.

If motor fails to start and the fuses do not blow, there may be a dead line; test for current.

In the case of a series motor there may be an open circuit in either armature or fields; this can be in the armature only if a shunt motor. Insufficient tension or poor contacts of brushes also often prevent the motor from starting. In an alternating current motor the frequency may be too high. One or more phases may be open.

Fields Running Hot.—The voltage at which machine operates may be higher than that for which it was intended. Fields may be in parallel where they were meant to be in series. A part of the field may

be short circuited, or cut out by grounding. In such a case one of the fields will be cool while the other runs abnormally hot.

Heating of Armature.—This may be caused by an overload; the heating increases as the square of the current used. There may be a short-circuited armature coil; if so, it will speedily show itself by burning out. A strong odor of heated shellac will probably be the first indication. Poor ventilation is often the cause; many motors are meant to operate either open or enclosed, and the enclosed capacity is always much less than the open.

Shaft of Bearings Running Hot.—This may result from improper oiling, boxes too tight, shaft bent, belts too tight, rough bearings, or the armature may not be properly centered, and thus press too hard on one of the end collars.

Shocks Obtained from Machine.—These may be due to static electricity or to grounding of some live part of the motor or the frame. The troubles from static electricity can be overcome by grounding the frame or fitting the belting with arresters.

Sparking of Brushes.—This may be due to wrong position of the brushes. With increasing load, the brushes of motors must be shifted against the direction of rotation, and, vice versa, with generators the opposite rule holds. The best motors, however, require very little shifting of brushes. Rough commutator, ragged brushes, or dirty condition of either commutator or brushes are frequent cause of sparking. Insufficient tension is also a frequent cause of sparking. If the brush is too narrow it will leave one segment before making the proper connection with the next; if too wide, it will short circuit too many and thus cause sparking. Incorrect spacing of brushes will cause sparking. Compound wound motors, or those operating with light field, are subject to much

sparking. To prevent this, inter-poles are often provided. Test direction of current in series winding by starting motor with shunt field open. An open circuit in an armature coil will cause severe sparking, which will occur only at a certain place on commutator.

Motors.—*Direct Current.*—There are three types of d. c. motors; viz., series, shunt, and compound.

The Series Motor.—Small series motors, such as fan motors, can be made to work successfully under any conditions. Large series motors with a variable load require constant attendance. Lightening the load will allow the motor to speed up inordinately and become dangerous. Such motors are very useful where heavy loads are to be started, as the torque is theoretically proportional to the square of the current as long as the fields are at a low point of saturation. And in all cases when the fields are not fully saturated, the torque increases faster than the current. The maximum torque exists at low speed and is independent of the voltage, depending entirely upon the current.

Shunt Motors.—The shunt motor is the most used of all direct current motors, and if properly constructed operates at a fairly uniform speed for all loads within its capacity. Once started it requires no attention. It is suitable for all classes of work, except such as street car service where the current is often suddenly interrupted and as suddenly thrown on again by accidents to the trolley. Its starting torque is not as good as that of the series motor, but it is fair. The field strength varies with the voltage, but as long as this is maintained it is independent of the voltage at armature terminals.

The Compound Motor.—This is a combination of shunt and series motor and has both windings. If the current in the compound winding is in the same direction as that in the shunt, the increased current

strength necessary to handle a heavy load will strengthen the fields and slow the motor down. Such a motor is known as "cumulative" and has a very good starting torque. If the compound winding is in the opposite direction, an increased current will lighten the fields and cause the motor to speed up, but will give it a poor starting torque. The compound winding may be so adjusted that the motor will run at a very even speed for all loads within its capacity. A motor so connected is known as "differential." Owing to the fact that part of the field magnetization is destroyed by the series winding, the efficiency is somewhat low. Commutating or inter-poles are often inserted in d. c. motors. Such poles are provided to overcome the armature reaction and produce sparkless commutation. Motors so equipped can carry greater overloads. They are very useful where a good starting torque is required. Motors are further divided into open and enclosed types. The capacity of a totally enclosed motor is only about 60 per cent of that of the open motor. The capacity in H. P. depends upon whether the motor is to be used continuously or intermittently, and is governed by the heating limitation, the heat generated being proportional to I^2.

The current required by any motor can be found by the formula

$$\text{Current} = \frac{\text{H. P. delivered} \times 746}{\text{efficiency} \times \text{voltage}}$$

The efficiency of a motor can be found by dividing the input by the output. All motors are delivering their maximum power when the speed is such that the counter e. m. f. of the motor is one-half of that delivered at the terminals.

Reversing Direction of Rotation.—All d. c. motors may be reversed by changing the connections of either field or armature so that current passes through one

of them in the opposite direction. If the current in both is reversed the direction of rotation will remain as before. Most multi-polar motors may be reversed by shifting the brushes sufficiently; this is equivalent to reversing armature leads.

Speed Control.—All d. c. motors tend to run at a speed which enables the armature to generate a counter e. m. f. equal to that of the supply. The speed can be varied by strengthening the field, which reduces it, or weakening the field to increase it. The commonest method of accomplishing speed control is by means of resistance cut into the armature circuit. This method, however, causes a speed variable with the load, the fall in pressure at the motor terminals being equal to IR. Adjusting the field strength to regulate the speed causes much sparking at the brushes. This can be obviated to a large extent by the use of commutating or inter-poles. The armature current passes around these and tends to keep the neutral point at a certain place, thus preventing sparking. Speed control is further effected by switching arrangements which enable one to connect several motors either in series or parallel; the parallel connection giving the higher speed and the series the lower. Such systems are used mostly in connection with d. c. street railway service.

Starting of d. c. Motors.—All d. c. motors, except the small ones which are wound with a high resistance in armature circuit, require some extra resistance to keep the current down until the armature has attained sufficient speed to generate the counter e. m. f. which finally limits the current. This resistance must never be in the field circuit of a shunt motor, but always in the armature circuit. In the differential motor, the series winding should be cut out of circuit until the motor is started, otherwise the excessive starting current will weaken the field too much. In the cumu-

lative type of motor, the series field adds to the starting torque. A motor may be tested as to whether it is cumulative or differential by starting it with the shunt field open. If cumulative it will run in the same direction as with the shunt field closed. The starting resistances of shunt motors are usually wound with fine wire which will overheat and burn out if left in circuit too long. Not more than thirty seconds should be consumed in manipulating the handle. In some cases, however, special apparatus is provided which can carry the current indefinitely. If motor does not start at once, open switch and look for the cause of trouble.

Power Required to Operate Machinery.—When the H. P. needed to operate a given machine is not known it may in some cases be calculated from the formula:

$$\text{H. P.} = \frac{P \times 2\pi \times r \times n}{12 \times 33{,}000 \times e}$$

where P = pull in pounds which must be applied at periphery of pulley to move it; r = radius of pulley in inches; n = number of revolutions per minute; e = the efficiency of a direct current motor or the product of efficiency and power factor in an alternating current motor or circuit.

If the machinery to be started is equipped with heavy flywheels, or possesses considerable inertia of any kind, the size of the motor needed is governed by the starting requirements which depend largely upon the rate of acceleration demanded. In connection with other machinery, such as ventilating fans for instance, the power required increases faster than the speed and can be measured only when the device is operating at full speed. For such motors the above formula cannot be used and it is necessary to obtain data from manufacturers or other users.

TABLE XXXXVII

To find H. P. required, multiply pull in pounds at periphery of pulley by number found where the given speed and radius cross.

Radii of Pulley in Inches

R.P.M.	2	3	4	5	6	7	8	9	10	11	12
100.....	.0042	.0063	.0085	.0106	.0127	.0149	.0170	.0190	.0212	.0233	.0254
200.....	.0085	.0127	.0170	.0212	.0255	.0298	.0340	.0381	.0424	.0467	.0510
300.....	.0127	.0190	.0254	.0318	.0381	.0447	.0508	.0570	.0636	.0699	.0762
400.....	.0170	.0255	.0340	.0424	.0508	.0596	.0680	.0765	.0848	.0933	.1016
500.....	.0212	.0318	.0424	.0530	.0635	.0745	.0848	.0954	.1060	.1165	.1270
600.....	.0255	.0382	.0510	.0636	.0762	.0894	.1020	.1146	.1272	.1399	.1524
700.....	.0298	.0447	.0596	.0742	.0889	.1043	.1192	.1341	.1484	.1631	.1778
800.....	.0340	.0510	.0680	.0848	.1016	.1192	.1360	.1530	.1696	.1766	.2032
900.....	.0382	.0573	.0764	.0954	.1143	.1341	.1528	.1719	.1908	.2000	.2286
1000.....	.0424	.0636	.0848	.1060	.1270	.1490	.1696	.1908	.2120	.2332	.2540

In the table below the values of $\frac{2\pi \times r \times n}{12 \times 33{,}000 \times e}$ (e being assumed as of about .75) are given wherever the horizontal line pertaining to speed crosses with a vertical line pertaining to radius of pulley.

Care must be exercised in determining P; it must not be more than just enough to cause motion, and at best can be only an approximation. P may be determined by a spring balance, or by a weight and lever. If the latter is used and attached to rim of pulley, multiply weight by distance from center of pulley and divide by radius of pulley.

Group vs. Individual Drive.—The total H. P. capacity of motors for individual drive must be equal to the H. P. demands of all the machinery.

The H. P. capacity for group drive may be considerably less, because not all of the driven machinery is used at the same time. How much of saving there is in any given case depends upon circumstances. Very often the shafting necessary with group drive requires as much additional H. P. capacity as is saved by the other consideration above.

The total H. P. required for group drive can be found by the formula:

$$\text{H. P.} = \frac{(h.p. \times f) + s}{e}$$

where h. p. is the horsepower demanded by the total machinery if run all at the same time; f is the load factor; s the H. P. required to drive shafting, and e the efficiency of the motor. The large motors used for group drive are more efficient at full load than the smaller ones, but a group drive motor is seldom run at full load. If it is properly chosen it will be overloaded part of the time and inevitably be running with no other load than the shafting part of the time.

The nearer it can be kept running with full load the more efficient it will be. The total H. P. required for individual drive is equal to the sum of the H. P. of all the machines divided by the efficiency. The full load efficiency of the small motors is lower, but there is never any idle machinery or shafting to be moved, and if properly selected the motors may operate at full load efficiency most of the time. In most cases individual drive is the most economical where a permanent installation is considered, but the cost of installation is generally somewhat higher. In addition to the above advantages, which can be figured out in dollars and cents, the following considerations should be of interest and duly noted: With individual drive the fire and life hazard are somewhat increased, but the shafting and belting accidents are greatly decreased. In connection with low voltage (110 or 220) the life hazard is small, and the advantage is on the side of the individual drive. With high voltage group drive is probably safer. With individual drive the facilities for speed regulation are better and motor troubles cannot throw a whole shop out of order. There is no shafting to cause dirt and noise and interfere with illumination, and there is less vibration in the workroom. Individual drive, however, requires somewhat more care and attention.

Where we have the choice of motors of different efficiencies we can afford to expend for the motor of the better efficiency a sum of money upon which the annual interest charge will be equal to the saving in the cost of energy effected by the better motor. We must, however, select the rate of interest so as to cover all depreciation, and if we assume that the motor will be a dead loss at the end of the time it is to be used, we shall obtain the following rates of interest, using a 6 per cent basis:

Motor to be used 1 year only,	106	per cent
2 years,	56	"
3 years,	40	"
4 years,	32	"
5 years,	27	"
6 years,	24	"
7 years,	$21\frac{1}{2}$	"
8 years,	20	"
9 years,	$18\frac{3}{4}$	"

For longer periods of time the interest rate decreases slowly and the above will cover all ordinary cases.

According to the above principles we can determine the amount of money we may economically invest in order to substitute a motor of higher efficiency for another with lower efficiency by the formula,

$$C = \frac{\text{K. W.} \times r \times h \times d \times e}{\text{per cent interest}}$$

where C = capital to be invested; K. W. = the number of watts used; r = the rate per K. W. hour; h = the number of hours K. W. is used per day; d = the number of days per year; e = the difference in efficiency of the two motors; per cent interest = the rate of interest governed by the number of years motor is to remain in use as given above.

In the following table it is assumed that the motor will be used 300 days per year, and on this basis the numbers given represent the capital which could profitably be invested with K. W., r, and h equal to unity, and e and the rate of interest as given in the table. To use the table for determining how much can profitably be invested to substitute a more efficient motor in place of a poorer one, it is but necessary to find the product of K. W. $\times r \times h$, and with this multiply the number found where the horizontal line pertaining to the difference in efficiency in favor of the better motor

TABLE XXXVIII

Number of Years Motor Is to Remain in Use

Efficiency	1 yr. 106	2 yrs. 56	3 yrs. 40	4 yrs. 32	5 yrs. 27	6 yrs. 24	7 yrs. 21½	8 yrs. 20	9 yrs. 18¾
1........	.0283	.0536	.0750	.0937	.1111	.1250	.1396	.1500	.1600
2........	.0566	.1172	.1500	.1874	.2222	.2500	.2792	.3000	.3200
3........	.0849	.1608	.2250	.2811	.3333	.3750	.4188	.4500	.4800
4........	.1132	.2144	.3000	.3748	.4444	.5000	.5584	.6000	.6400
5........	.1415	.2680	.3750	.4685	.5555	.6250	.6980	.7500	.8000
6........	.1698	.3216	.4500	.5622	.6666	.7500	.8376	.9000	.9600
7........	.1981	.3752	.5250	.6559	.7777	.8750	.9772	1.050	1.120
8........	.2264	.4288	.6000	.7496	.8888	1.000	1.127	1.200	1.280
9........	.2547	.4824	.6750	.8433	.9999	1.125	1.256	1.350	1.440
10........	.2830	.5360	.7500	.9370	1.111	1.250	1.396	1.500	1.600
12........	.3396	.6432	.9000	1.124	1.332	1.500	1.675	1.800	1.920
14........	.3962	.7504	1.050	1.312	1.554	1.750	1.954	2.100	2.220
16........	.4528	.8576	1.200	1.499	1.776	2.000	2.254	2.400	2.560
18........	.5094	.9648	1.350	1.686	1.998	2.250	2.512	2.700	2.880
20........	.5630	1.072	1.500	1.874	2.222	2.500	2.792	3.000	3.200

TABLE XXXXVIII—Continued

Efficiency	1 yr. 106	2 yrs. 56	3 yrs. 40	4 yrs. 32	5 yrs. 27	6 yrs. 24	7 yrs. 21½	8 yrs. 20	9 yrs. 18¾
22........	.6226	1.179	1.650	2.061	2.444	2.750	3.071	3.300	3.520
24........	.6792	1.286	1.800	2.248	2.664	3.000	3.350	3.600	3.840
26........	.7358	1.394	1.950	2.436	2.888	3.250	3.629	3.900	4.160
28........	.7924	1.501	2.100	2.624	3.108	3.500	3.908	4.200	4.480
30........	.8490	1.608	2.250	2.811	3.333	3.750	4.188	4.500	4.800
32........	.9056	1.715	2.400	2.998	3.552	4.000	4.467	4.800	5.120
34........	.9622	1.822	2.550	3.188	3.774	4.250	4.746	5.100	5.440
36........	1.018	1.929	2.700	3.372	3.996	4.500	5.025	5.400	5.760
38........	1.074	2.036	2.850	3.560	4.222	4.750	5.304	5.700	6.080
40........	1.132	2.144	3.000	3.748	4.444	5.000	5.584	6.000	6.400
42........	1.188	2.251	3.150	3.936	4.662	5.250	5.862	6.300	6.720
44........	1.245	2.358	3.300	4.122	4.888	5.500	6.142	6.600	7.040
46........	1.302	2.466	3.450	4.320	5.111	5.750	6.420	6.900	7.360
48........	1.358	2.572	3.600	4.496	5.328	6.000	6.700	7.200	7.680
50........	1.415	2.680	3.750	4.685	5.555	6.250	6.980	7.500	8.000

Rule: Find the difference in efficiency between motors under consideration; also the number of years motor is to be used. Select number found where lines pertaining to difference in efficiency and years of use cross and multiply this number by K. W. hours per day and rate per K. W. The result will give the number of dollars which may be invested to procure the motor of higher efficiency.

crosses with the rate of interest applicable to the problem. The result will be the sum in dollars and cents which can with profit be expended to procure the better motor.

Rule of Table.—Find the difference in efficiency between the motors considered and the number of years the motor is to be used. Select the number found in the longitudinal line where the corresponding efficiency (given in vertical column at the left) crosses with the proper rate of interest (given at top); multiply this number by the K. W. hours per day, and by the rate per K. W. The result will give the amount of money which may be invested to procure the motor of higher efficiency. If this sum will make up the difference in cost, the better motor should be provided.

Nails.—Use cut nails for driving into brickwork.

TABLE XXXXIX

Dimensions of Nails

		Common Nails			Finishing Nails		
Size	**Length**	Nearest **B. & S.**	Diam. in inches	Approx. number per lb.	Nearest **B. & S.**	Diam. in inches	Approx. number per lb.
2d	1	13	9/128	876	14	8/128	1351
3d	1¼	12	5/64	568	13	9/128	807
4d	1½	10	7/64	316	13	9/128	584
5d	1¾	10	7/64	271	13	9/128	500
6d	2	9	7/64	181	11	3/32	309
7d	2¼	9	7/64	161	11	3/32	238
8d	2½	8	17/128	106	10	7/64	189
9d	2¾	8	17/128	96	10	7/64	172
10d	3	7	19/128	69	9	7/64	121
12d	3¼	6	19/128	63	9	7/64	113
16d	3½	6	5/32	49	8	17/128	90
20d	4	4	25/128	31	8	17/128	62
30d	4½	4	27/128	24			
40d	5	3	29/128	18			
50d	5½	2	31/128	14			
60d	6	2	33/128	11			

National Electrical Code (*Abbreviated N.E.C.*).—The N. E. C. contains the recommendations of the National Fire Protection Association in reference to electrical installations. It is revised every two years, and its recommendations are generally accepted as standard throughout the United States. Most municipalities pattern their regulations after this code, but introduce a few variations which local conditions seem to warrant. The National Board of Fire Underwriters issue "The List of Electrical Fittings." This contains a list of appliances which have been tested and are considered safe. Those engaged in electrical construction work are advised to keep in touch with the N. E. C., the List of Electrical Fittings, and local requirements.

Nernst Lamp.—This lamp is not as much used as formerly. It has a high intrinsic brilliancy; requires no reflectors; should be hung high. It requires considerable attention to keep in repair and cannot be used in theatres or similar places where quick changes are necessary.

Neutral Wire.—This term describes one of the three wires used in connection with the three-wire system. Normally this wire carries no current and is, therefore, often smaller than either of the outside wires. In case an outside fuse blows, it may, however, be called upon to carry the full load current. It is always fused higher than the outside wires, and often is not fused at all. Blowing of the neutral fuse may do much damage. Ordinarily this wire is also grounded.

In a star connected polyphase system, the point at which all of the wires connect is also spoken of as neutral. The fourth wire in a three-phase system may also be so termed.

Non-Inductive Load.—A non-inductive load is distinguished from an inductive load by the fact that

the current is in phase with the voltage. Circuits supplying only incandescent lamps are very nearly non-inductive; arc lamps and motors make up a strongly inductive load.

Office Lighting.—Desk lights are very common, but they are also a nuisance. They cause constant annoyance, and increase the fire hazard.

Inverted lighting is very favorably received in many offices and deserves extended trials. The newer high efficiency lamps have done much to make it economical. Where all employes are constantly at their desks there can be no difference of opinion regarding the superiority of a good general illumination in every respect. Local illumination can appear advisable only in such places where most of the desks are occupied for a short time per day only.

Avoid large spreading chandeliers carrying many lamps. These often cause a multiplicity of shadows. If clusters are used, lamps should be close together. Do not run wires in any but the main walls or partitions; use three-fourths inch conduit so as to have plenty of capacity for changes which are always taking place. Arrange lighting to harmonize with windows, so that furniture placed correctly for daylight will also fit the artificial illumination.

Ohm.—The international ohm has been legalized in this country and is defined as the resistance which a column of mercury of a uniform cross section, at the temperature of melting ice, and 106.3 centimeters in length, and of a mass of 14.4521 grams, offers to an unvarying electric current.

Ohms Law.—$I=\frac{E}{R}$; $I\times R=E$; $R=\frac{E}{I}$

Ohmic Loss or Drop.—The loss in e. m. f. or drop in p. d. caused by the resistance as distinguished from that caused by reactance.

Overhead Construction.—The timbers most in use for poles are: Michigan cedar, Western cedar, chestnut, pine and cypress. Of these the cedars and chestnut are the most used. The cedars are easier to climb and the taper is greater so that the tops of cedar poles are smaller in proportion to the butts than chestnut poles. On account of the variable nature of the wood and the fact that they soon begin to rot at the ground line, which is the point of greatest strain, the strength of poles must be calculated with a large factor of safety. In the tables following the breaking strain of the wood has been taken as 7,000 pounds per square inch and a factor of safety of 10 has been used.

Poles are usually designated by their length in feet and diameter at top in inches; thus a pole 40 feet long and 8 inches in diameter at top is spoken of as a 40-8 pole. The standard or most used pole is 35 feet long and has a 7-inch top. In swampy places poles are often set in concrete.

Poles should be set with the sweep in the line so that the wires may be straight. Use no iron poles where lines must be worked on while alive. Set pole steps 32 inches apart and stagger them. In cities place poles on lot lines. Avoid placing poles near lamp posts, hydrants or catch basins. Give corner poles a slight rake outward. Use the heaviest poles for transformers. Special attention should be given to tamping at bottom and top of holes, and the earth should be piled up a little around pole to keep water from running in. Keep one side of pole free for climbing. Double arm all poles subject to unusual strains. The lowest cross arm should be at least 18 feet above ground and 22 feet above railway tracks. Allow at least 2 feet between cross arms; more if possible. Insulate guy wires. Make cross arms of uniform length.

Standard cross arms are rounded on top; $3\frac{1}{4}$ inches wide by $4\frac{1}{4}$ inches high; allow 24 inches between pole pins, and at least 12 inches between other pins; this distance varies with number of pins, length of span and voltage. Junction arms usually have a wider spacing between inside pins. The high tension wires should be carried on the top arms; secondary wires are usually run below them, and the lowest arms are left for signal wires if any are to be run on same line. There should be a space of about five feet between the signal and the lighting and power wires. The lowest voltage wires are usually run next to poles; circuit wires should be kept together, and neutral of three-wire system should be run in center. The fourth wire of a three-phase system is also carried next to pole.

Pole Line Calculations.—The first step in laying out a pole line must be to decide upon height of poles and maximum span lengths. The next step will be to calculate the strains to which poles may be subject. The main body of a pole line is subject only to wind pressure, and this can be determined by use of Table LII. End poles are subject to half of this wind pressure and strain from the wires as well. Poles from which taps are taken have the full wind pressure and strain of wires leading off. Corner poles must be considered as subject to 1.41 times the strain on end poles. The wire strains upon poles can be found by the use of Table LI. The strains upon poles having been determined, the proper diameter at ground line can be determined by Table LIII.

When the strains on a pole are found to be greater than a pole of desirable diameter can well bear, it must be reinforced by guying or bracing. The proper diameter of guy cables can be found from Tables LV to LVII. If the pole is light compared to the strain put upon it, it will be best to provide a guy cable to take care of the total strains.

TABLE L

It is common practice to string electric power wires in accordance with the following tabulation, which gives the sag in inches:

Length of span	Temperature in Fahrenheit 20°	30°	40°	50°	60°	70°	80°	90°
50....	8	8	9	9	10	11	11	12
60....	9	10	11	11	12	13	14	14
70....	10	11	12	13	14	15	16	17
80....	12	13	14	15	16	17	18	19
90....	14	14	16	17	18	19	20	21
100....	16	16	17	19	20	21	23	24
110....	18	18	19	21	22	24	25	26
120....	18	19	21	23	24	26	27	28
130....	20	22	24	26	28	30	32	33
140....	22	23	26	28	30	32	34	35
160....	24	26	28	30	32	34	36	38

With wires strung according to the above tabulation each wire at the lowest temperature given will cause a strain on poles as given below. To find total strain on pole multiply proper number in table below by number of wires. By allowing a greater sag the strain will be proportionately reduced.

TABLE LI

Bare Copper

Length of Span	B. & S. Gauge 14	12	10	8	6	5	4	3	2	1	0	00	000	0000
80	10	16	26	47	63	80	101	127	160	202	255	321	405	512
100	13	22	34	62	85	107	135	171	215	272	343	432	545	688
120	15	24	39	70	95	120	151	190	240	303	382	481	607	768
140	18	29	47	85	116	147	182	230	294	371	470	592	740	942
160	19	32	52	94	126	160	202	254	320	404	510	642	810	1024

Breaking Strains

B. & S. Gauge

	14	12	10	8	6	5	4	3	2	1	0	00	000	0000
Hard Drawn—	219	343	546	843	1300	1580	1900	2380	2970	3680	4530	5440	6530	8260
Annealed—	110	174	277	441	700	884	1050	1323	1670	2100	2650	3310	4270	5320

Insulation and sleet may easily treble the strains.

The Maximum wind pressure upon the pole alone will range from 125 to 250 lbs., according to length and diameter of pole.

The side strain on a straight pole line (125 ft. span) can be found by use of the table below. Multiply number of wires on pole by number found under size of wire and in proper horizontal line.

TABLE LII

Wind Pressure

B. & S.	14	12	10	8	6	5	4	3	2	1	0	00	000	0000
Bare wire..	8	11	13	19	22	26	29	32	36	40	45	50	55	60
Insulated ..	35	38	41	46	50	53	56	60	65	70	80	90	100	110

Sleet may easily treble these strains, but sleet seldom exists in stormy weather.

TABLE LIII

Table showing maximum strains (applied at top) to which poles of various heights above ground, and of various diameters at ground line, should be subject.

Dia. of pole at ground line in inches	Height of Poles Above Ground in Feet										
	20	25	30	35	40	45	50	55	60	65	70
8..	147	118	98	84	74	66	58	53	49	46	42
9..	209	168	138	120	105	93	83	76	70	65	60
10..	286	228	191	164	143	127	115	104	95	88	81
11..	381	304	254	218	191	169	152	138	127	117	109
12..	495	396	330	284	247	220	198	180	165	121	141
13..	624	500	416	356	312	278	250	226	208	192	178
14..	786	628	524	450	393	350	314	287	262	242	224
15..	960	768	640	548	480	427	384	349	320	296	274
16..	1176	940	784	672	588	524	470	428	392	362	336
17..	1407	1124	938	804	704	625	563	572	469	433	402
18..	1658	1328	1106	948	828	756	664	604	553	510	474
19..	1964	1572	1310	1120	982	872	786	716	655	604	562
20..	2288	1831	1526	1284	1144	916	915	832	763	704	652
21..	2665	2132	1764	1524	1333	1144	1066	968	885	820	762
22..	3048	2440	2032	1740	1524	1356	1209	1108	1016	938	870

Depth of Setting

Earth	5	5½	6	6	6½	6½	7	7½	8	8½	9
Rock	4	4½	5	5	5½	5½	6	6½	7	7	9½

When erected along a curved line it is best to set somewhat deeper.

TABLE LIV

The following table probably shows the average of poles used for general telegraph and telephone purposes:

Length	Butt Dia.	Top Dia.	Wt. App.	Length	Butt Dia.	Top Dia.	Wt. App.
25...	9 to 10	6 to 8	350	50...	9 to 15	6 to 8	1350
30...	9 to 11	6 to 8	450	55...	16 to 17	6 to 8	1700
35...	9 to 12	6 to 8	600	60...	16 to 18	6 to 8	2200
40...	9 to 13	6 to 8	850	65...	16 to 19	6 to 8	2500
45...	9 to 14	6 to 8	1100	70...	16 to 20	6 to 8	3000

Guys.—Guys should be fastened to pole at point of strain and when so fastened the strain upon the guy can be found by the formula

$$S = \frac{\sqrt{D^2 + H^2}}{D} \times P$$

where D = horizontal distance at ground of guy from pole; H = the height of guy, and P = the pull upon the pole.

TABLE LV

Table for Calculating Strength of Guys.—To find the proper size of wire or wire rope for guying, multiply total strain upon pole by number found at point where line pertaining to height of guy fastening on pole crosses with line pertaining to horizontal distance of guy at ground from pole. The product will equal the breaking strain of the proper cable or wire to be used. The table is calculated for a safety factor of 5.

Height of guy on pole	Horizontal distance in feet from pole to where the guy or its support leaves ground 5	10	15	20	30	40	50
10......	11	7.0	6.2	5.5	5.3	5.2	5.1
15......	16	9.0	7.0	6.2	5.6	5.3	5.2
20......	21	11	8.3	7.0	6.0	5.6	5.5
30......	31	16	11	9.0	7.0	6.3	5.8
40......	40	21	15	11	8.3	7.0	6.5
50......	50	26	18	14	9.5	8.0	7.0
60......	60	31	21	16	11	9.0	7.6
70......	70	36	24	18	13	10	8.5

TABLE LVI

Table Showing Breaking Strain of Cables and Wires.—Standard Steel Strand. American Steel and Wire Company. Seven steel galvanized wires twisted into a single strand. Galvanized or extra galvanized.

Dia. in inches	Approx. Weight per 1000 feet	Approx. Strength in pounds	Galvanized Steel Wire A. S. & W. G.	Dia.	Breaking Strain	Nearest B. & S.	Dia.
$\frac{5}{8}$	800	14000	12	.106	510	10	.102
$\frac{9}{16}$	650	11000	10	.135	774	8	.128
$\frac{1}{2}$	510	8500	9	.148	942	7	.144
$\frac{7}{16}$	415	6500	8	.162	1170	6	.162
$\frac{3}{8}$	295	5000	6	.192	1770	5	.182
$\frac{5}{16}$	210	3800	5	.207	2079	4	.204
$\frac{1}{4}$	125	2300	4	.222	2433	3	.229
$\frac{7}{32}$	95	1800	The American Steel and Wire gauge is commonly used for iron wire.				
$\frac{3}{16}$	75	1400					
$\frac{5}{32}$	55	900					

TABLE LVII

When a pole or mast is held in place by several guys equally spaced the figures obtained by the above calculation may be divided by the following guy factors taken from publication of the American Steel and Wire Company:

No. guys	Min. value of guy factor	Corresponding line of action of force	Max. value of guy factor	Corresponding line of action of force
3	0.866	30° from 1 guy	1.000	Opposite 1 guy or half way between two
4	1.000	Opposite 1 guy	1.414	Half way between 2 guys
5	1.538	18° from 1 guy	1.618	Opposite 1 guy or half way between two
6	1.732	30° from 1 guy	2.000	Opposite 1 guy

Telephone Wires.—The tables below give the practice of the A. T. & T. Co. No. 12 hard drawn copper wires are strung according to the following table:

TABLE LVIII

Temp. in Degrees F.	Length of Span in Feet 75	100	115	130	150	175	200	250	300
	Sag in Inches								
— 30	1	2	2½	3½	4½	6	8	14	22
— 10	1½	2½	3	4	5	7	9	16	25½
+ 10	1½	3	3½	4½	6	8	10½	18½	29½
+ 30	2	3½	4	5½	7	9½	12	21	33
+ 60	2½	4½	5½	7	9	12	16	26½	42½
+ 80	3	5½	7	8½	11½	15	19	31	49
+100	4½	7	9	11	14	18	22½	36	55

The same sag is also allowed for iron wire.

Messenger Cables.—The standard messenger strands used are the following:

Size of Cable No. 22 Gauge	No. 19 Gauge	Strength of Strand
100 pair or smaller	50 pair or smaller	6000 lbs.
100 to 200 pair	55 to 100 pair	10000 lbs.
Larger than 200 pair	Larger than 100 pair	16000 lbs.

The above strands are about equivalent to $\frac{7}{16}$, $\frac{9}{16}$ and $\frac{5}{8}$ inch diameters of good quality steel and used for spans not exceeding 200 feet.

The sag allowed is the following:

Span in feet	Sag in inches for heavy cables	Sag in inches when not more than 50 pair No. 22 gauge wire will be used
80	16	10
90	20	12
100	22	16
110	26	18
120	30	20
130	34	22
140	40	26
150	44	30
175	62	42
200	82	58

Panel Boards.—The panel board is a small switchboard, but circuits supplying more than 660 watts are seldom fed through it. Those described in the following figures and tables are designed for 660-watt branch circuits. Main bars have a capacity of 6 amperes per branch circuit at 110 volts, but only 3 amperes if designed for 220 volts. The figures in the tables are those furnished by the Cuthbert Electric Mfg. Co. Wherever the depth of cabinet required is the same for all numbers of circuits, it has been given in the fourth column from the left. In other cases the special designations at each height will serve as a guide. Where no special mark is placed and no depth given, the required depth is $3\frac{1}{2}$ inches. When ordering boxes, see points to be noted under *Cabinets*.

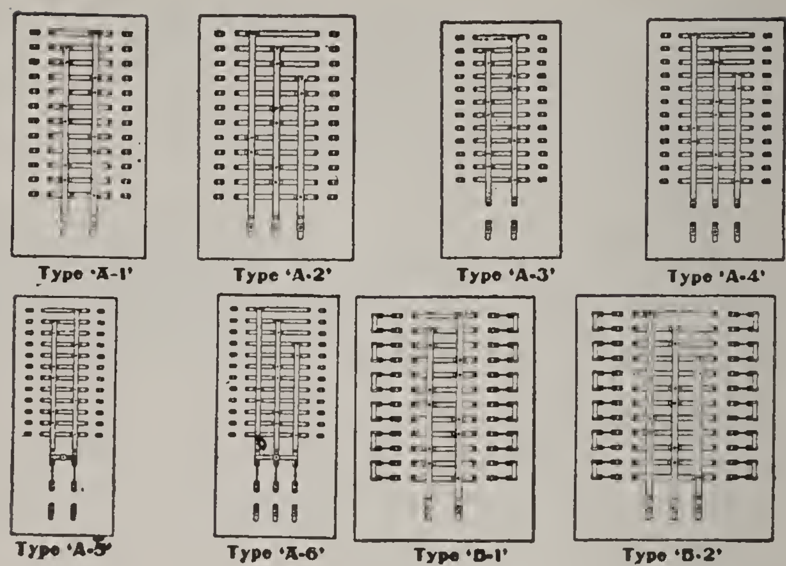


Figure 12.—Types of Panel Boards.

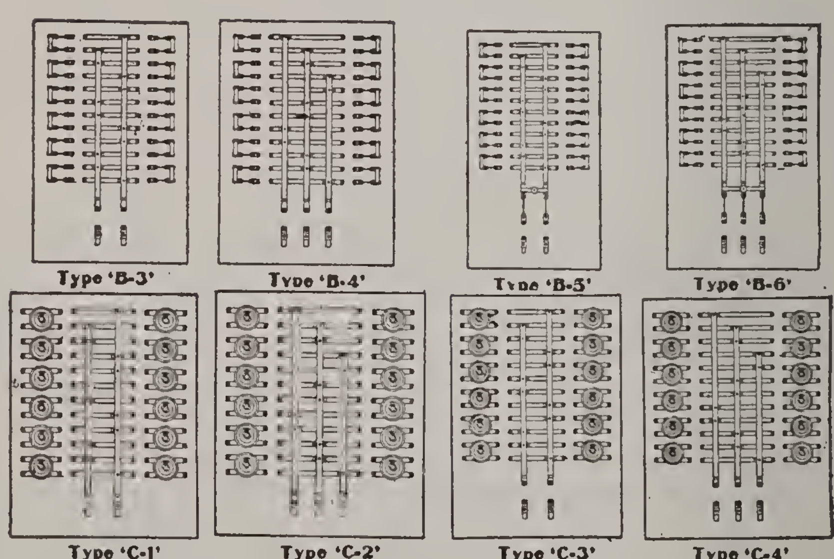


Figure 13.—Types of Panel Boards.

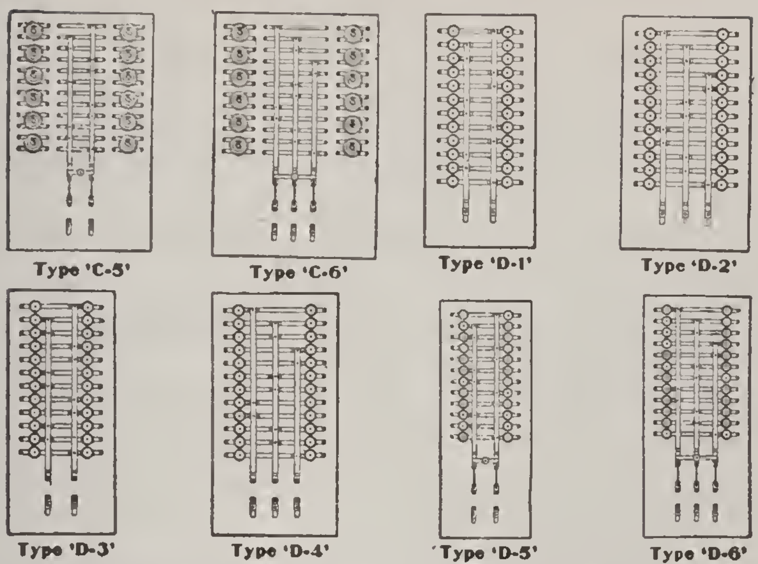


Figure 14.—Types of Panel Boards.

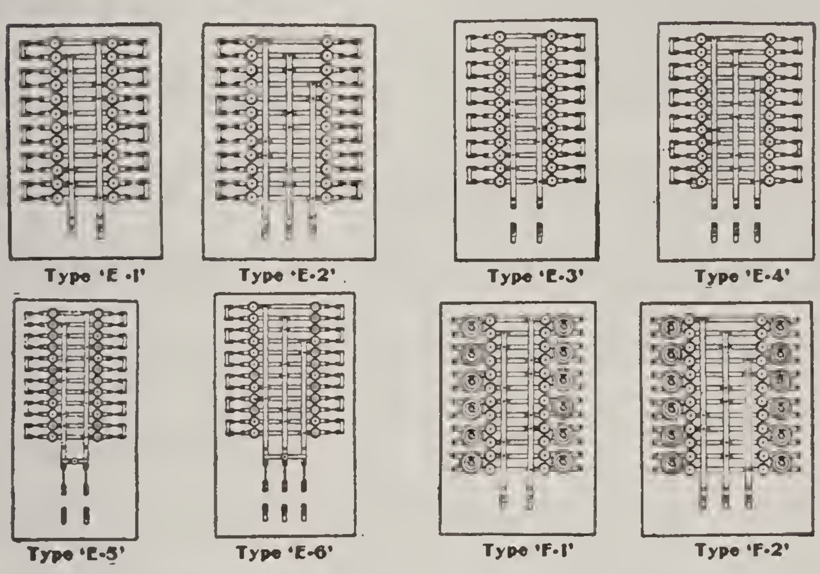


Figure 15.—Types of Panel Boards.

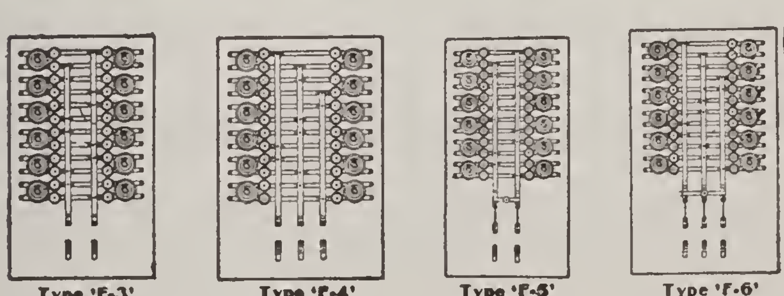


Figure 16.—Types of Panel Boards.

TABLE LIX

Dimensions of Panel Boards Cuthbert Electric Mfg. Co., Chicago
+4½ inches deep cabinet. △5½ inches deep. 3 wire 250 volts for 3 phase. See Figures 12 to 16.

Number of Circuits

Type	Volts	Wid.	Depth	4	6	8	10	12	14	16	18	20	22	24	26	28	30
'A-1'	125	10	3½	10	13	16	18	21	24	26	29	32	35	37	40	42	45
	250	10	3½	11	15	19	23	26	30	34	37	41	45	48	51	55	58
'A-2'	125	12	3½	10	12	15	18	21	23	26	28	31	33	36	39	41	43
	250	12	3½	12	16	20	25	29	33	37	41	45	49	53	57	61	65
'A-3'	125	10		12	16	19	24	27	29	32	34+	40+	42+	45+	47+	50+	52+
	250	10		14	17	21	26	30	33	37	40	47	50	54	57+	61+	64+
'A-4'	125	12		12	15	17	21	24	26	29	31	37	39	42	44	47+	49+
	250	12		14	18	22	28	32	36	40	44	51	55	59	63	67+	71+
'A-5'	125	10		15	21+	23+	29+	31+	35	38	40	44	47	49	52△	54△	57△
	250	10		16	20	23	30+	34+	37+	41+	44+	51+	55+	58+	63△	66△	70△
'A-6'	125	12		15	17	20	26+	28+	31+	33+	36+	41+	44+	46+	50+	52△	55△
	250	12		17	21	25	32+	36+	40+	44+	48+	55+	59+	63+	68+	72△	76△
'B-1'	125	14	4½	10	13	16	18	21	24	26	29	32	35	37	40	42	45
	250	16	5½	12	16	19	24	27	31	35	39	42	46	50	54	57	61
'B-2'	125	16	4½	10	12	15	18	21	23	26	28	31	33	36	39	41	43
	250	18	5½	13	17	22	27	32	36	41	45	50	54	59	63	68	72
'B-3'	125	14	4½	12	16	19	24	27	29	32	34	40	42	45	47	50	52
	250	16	5½	14	18	21	25	31	34	38	42	48	52	56	60	63	67
'B-4'	125	16	4½	12	15	17	21	24	26	29	31	37	39	42	44	47	49
	250	18	5½	15	19	24	30	35	39	44	48	56	60	65	69	74	78
'B-5'	125	14		15+	21+	23+	29+	31+	35△	38△	40△	44△	47△	49△	52△	54△	57△
	250	16	5½	17	20	24	31	35	39	42	46	53	56	60	65	69	73
'B-6'	125	16		15+	17+	20+	26+	28+	31+	33+	36+	41+	44+	46+	50+	52△	55△
	250	18	5½	18	22	26	35	39	44	48	53	60	65	69	75	79	84

TABLE LX

Dimensions of Panel Boards—Continued

Cuthbert Electric Mfg. Co., Chicago

+4½ inches. △5½ inches. 3 wire 250 volts for 3 phase. See Figures 12 to 16.

				Number of Circuits													
Type	Volts	Wid.	Depth	4	6	8	10	12	14	16	18	20	22	24	26	28	30
'C-1'	125	16	3½	10	13	16	18	21	24	26	29	32	35	37	40	42	45
	250	16	3½	11	15	19	23	26	30	34	37	41	45	48	51	55	58
'C-2'	125	18	3½	10	12	15	18	21	23	26	28	31	33	36	39	41	43
	250	18	3½	12	16	20	25	29	33	37	41	45	49	53	57	61	65
'C-3'	125	16		12	16	19	24	27	29	32	34+	40+	42+	45+	47+	50+	52+
	250	16		14	17	21	26	30	33	37	40	47	50	54	57+	61+	64+
'C-4'	125	18		12	15	17	21	24	26	29	31	37	39	42	44	47+	49+
	250	18		14	18	22	28	32	36	40	44	51	55	59	63	67+	71+
'C-5'	125	16		15	21+	23+	29+	31+	35△	38△	40△	44△	47△	49△	52+	54+	57+
	250	16		16	20	23	30+	34+	37+	41+	44+	51+	55+	58+	63+	66+	70+
'C-6'	125	18		15	17	20	26+	28+	31+	33+	36+	41+	44+	46+	50+	52△	55△
	250	18		17	21	25	32+	36+	40+	44+	48+	55+	59+	63+	68+	72△	76△
'D-1'	125	8	4½	11	15	18	21	24	27	30	34	38	41	44	47	51	54
	250	8	4½	11	15	19	23	26	30	34	37	40	45	48	51	55	58
'D-2'	125	10	4½	11	14	17	21	24	27	30	33	37	40	43	46	49	52
	250	10	4½	12	16	20	25	29	33	37	41	45	49	53	57	61	65
'D-3'	125	8	4½	13	18	21	27	30	33	36	40	45	47	52	55	58	61
	250	8	4½	14	17	21	26	30	33	37	40	47	50	54	57	61	64
'D-4'	125	10	4½	13	16	19	24	27	30	33	37	43	46	49	52	55	58
	250	10	4½	14	18	22	28	32	36	40	44	51	55	59	63	67	71
'D-5'	125	8		15+	22+	25+	31+	35+	39△	42△	45△	50△	53△	56△	59△	62△	66△
	250	8		16+	20+	23+	30+	34+	37+	41+	44+	51+	55+	58+	63△	66△	70△
'D-6'	125	10		15+	19+	22+	28+	31+	35+	38+	41+	47+	50+	53+	58+	61△	64△
	250	10		17+	21+	25+	32+	36+	40+	44+	48+	55+	59+	63+	68+	72△	76△

TABLE LXI

Dimensions of Panel Boards—Continued

Cuthbert Electric Mfg. Co.

+4½ inches. △5½ inches. 3 wire 250 volts for 3 phase. See Figures 12 to 16.

Number of Circuits

Type	Volts	Wid.	Depth	4	6	8	10	12	14	16	18	20	22	24	26	28	30
'E-1'	125	12	4½	11	15	18	21	24	27	30	34	38	41	44	47	51	54
	250	14	4½	12	16	19	24	27	31	35	39	42	46	50	54	57	61
'E-2'	125	14	4½	11	14	17	21	24	27	30	33	37	40	43	46	49	52
	250	16	4½	13	17	22	27	32	36	41	45	50	54	59	63	68	72
'E-3'	125	12	4½	13	18	21	27	30	33	36	40	45	47	52	55	58	61
	250	14	4½	14	18	21	25	31	34	38	42	48	52	56	60	63	67
'E-4'	125	14	4½	13	16	19	24	27	30	33	37	43	46	49	52	55	58
	250	16	4½	15	19	24	30	35	39	44	48	56	60	65	69	74	78
'E-5'	125	12		15+	22+	25+	31+	35+	39△	42△	45△	50△	53△	56△	59△	62△	66△
	250	14		17+	20+	24+	31+	35+	39+	42△	46+	53+	56+	60+	65△	69△	73△
'E-6'	125	14		15+	19+	22+	28+	31+	35+	38+	41+	47+	50+	53+	58+	61△	64△
	250	16		18+	22+	26+	35+	39+	44+	48+	53+	60+	65+	69+	75+	79△	84△
'F-1'	125	12	4½	11	15	18	21	24	27	30	34	38	41	44	47	51	54
	250	12	4½	11	15	19	23	26	30	34	37	41	45	48	51	55	58
'F-2'	125	14	4½	11	14	17	21	24	27	30	33	37	40	43	46	49	52
	250	14	4½	12	16	20	25	29	33	37	41	45	49	53	57	61	65
'F-3'	125	12	4½	13	18	21	27	30	33	36	40	45	47	52	55	58	61
	250	12	4½	14	17	21	26	30	33	37	40	47	50	54	57	61	64
'F-4'	125	14	4½	13	16	19	24	27	30	33	37	43	46	49	52	55	58
	250	14	4½	14	18	22	28	32	36	40	44	51	55	59	63	67	71
'F-5'	125	12		15+	22+	25+	31+	35+	39△	42△	45△	50△	53△	56△	59△	62△	66△
	250	12		16+	20+	23+	30+	34+	37+	41+	44+	51+	55+	58+	63△	66△	70△
	250	14		17+	21+	25+	32+	36+	35+	38+	41+	47+	50+	53+	58+	61△	64△
'F-6'	125	14		15+	19+	22+	28+	31+	40+	44+	48+	55+	59+	63+	68+	72△	76△

Plans.—Except in the case of large office buildings, hotels, street lighting, and other large undertakings, detailed plans cannot show much more than location of outlets and most of the information is gathered from specifications. In large installations it is customary to designate sizes of conduit as well as the wires. In making the installation according to such plans the work is often subdivided, separate plans being given to different workmen or groups of workmen. If each group is allowed to finish its particular installation a very reliable check on the labor performed by each man or group is obtained.

Small plans are usually drawn to a scale of $\frac{1}{4}$ inch per foot; for large plans the scale is often $\frac{1}{8}$ inch, or even less. Details are drawn to a larger scale and sometimes even full size.

Power.—This term expresses merely the rate of doing work. In order to obtain the quantity, it must be multiplied by time. Power is measured in watts and is usually expressed in watt hours, kilowatt hours, or horsepower hours, but any other length of time may be chosen.

Preservation of Wood.—This is effected by impregnating the timber with some sort of poison which destroys the fungi and deprives them of food. Creosote is the most used, and there are various patented substances of a similar nature. The more thoroughly dried the timber is at time of application, the more it will absorb. Ordinarily the preservative is applied with a brush, but it is also applied under pressure, the whole pole or tie being submerged in a tank full of the impregnating material, to which pressure can be applied.

Printing.—Printing presses are usually equipped with reversible and variable speed motors. For the larger sizes several motors are used. All of these are preferably fitted with remote control switches which

enable the operator to govern the press from various points on and about it. Time is a very important consideration about large presses and the very best illumination should be supplied. On many presses from 10 to 20 lights are permanently installed so as to be ready at a moment's notice and obviate the necessity of using portable lamps. Such lights also assist in watching the mechanism while at work. Flexible conduit is serviceable, but it should be lead covered to guard against machine oil, which dissolves rubber.

Composing Rooms.—A good general illumination is advisable in composing rooms, but there must be local illumination with it in certain places. In some composing rooms the work is of such a nature that it is advisable to fit each stand with a foot or arm switch by which a compositor can turn the light on or off without using his hands.

Pumping.—One cubic foot of water weighs approximately 62.5 pounds and contains about 7.5 gallons. One gallon weighs 8.33 pounds and contains 231 cubic inches. If the head of a column of water is expressed in feet and the pressure at the foot of the column in pounds per square inch, then

$$\text{Head} = 2.31 \times \text{pressure}$$

$$\text{Pressure} = \text{head} \div 2.31, \text{ which equals } 0.434 \times \text{head},$$

and this is independent of size of column.

The H. P. required to deliver a certain quantity of water to a certain height is directly proportional to the product of the two if the so-called "friction head" is added to the actual height of lift. The friction head for various sizes of pipe and rate of flow through them is given in Table LXII. This friction head varies with the square of the velocity of the liquid, with the distance it flows, and with the conditions affecting its freedom of movement. Elbows, bends, burs, etc., increase it. The enormous losses in pres-

sure which take place when a small pipe is used for the delivery of a large amount of water can be seen from the table. The efficiency of centrifugal pumps is sometimes as low as 35 per cent, and that of rotary and plunger pumps ranges from 60 to 80.

Table LXII shows the resultant net efficiency of motors and pumps of various efficiencies working together.

From Table LXII we can take the number of cubic feet, pounds and gallons which one horsepower will lift to a height of one foot, the machinery having a net efficiency as given.

Rule for Determining Horsepower Needed.—Add to the actual head in feet the friction head as found in Table LXII and multiply this by the number of cu. ft., lbs. or gals., as the case may be. Next divide this sum by the number found in same table under the efficiency of the combination to be used; combined motor and pump efficiency.

Table showing number of cu. ft., lbs., or gals. which can be raised 1 foot per minute by 1 H.P. at efficiencies given.

TABLE LXII

Combined Motor and Pump Efficiency.

	64	60	56	52	48	46	43	40
Cu. Ft.	338	316	296	275	253	243	227	211
Lbs..	21,120	19,800	18,480	17,160	15,840	15,180	14,190	13,200
Gals..	2,535	2,370	2,220	2,062	1,897	1,822	1,702	1,582

Combined Motor and Pump Efficiency.

	38	36	34	32	30	28	26	24
Cu. Ft.	200	190	180	169	158	148	137	127
Lbs..	12,500	11,880	11,220	10,560	9,900	9,240	8,580	7,920
Gals.	1.500	1,425	1,350	1,267	1,185	1,110	1,027	952

TABLE LXII—Continued

Friction head per hundred feet of pipe of inside diameters given. Condensed from Westinghouse Electric & Mfg. Co. table.

			Inside Diameters of Pipes.						
Cu. Ft.	Lbs.	Gals.	¾″	1″	1¼″	1½″	2″	2½″	3″
0.6	37	5	7.59	1.93	0.71	0.27			
1.1	75	10	29.9	10.26	2.41	1.08			
1.6	112	15	66.01	16.05	5.47	2.23			
2.4	150	20	115.92	28.29	9.36	3.81			
3.0	187	25		43.70	14.72	5.02	1.18		
3.4	225	30		63.25	21.04	8.62	2.09		
4.2	263	35		85.10	28.52	11.61	2.76		
4.8	300	40		110.40	37.03	14.99	3.68	1.19	
5.2	338	45			46.46	18.74	4.60	1.49	
6.0	375	50			57.27	23.00	5.61	1.86	0.80
9.0	562	75			129.09	51.52	12.23	4.14	1.70
12.0	750	100				89.70	21.75	7.36	3.01
15.0	937	125					34.27	11.24	4.57
18.0	1,125	150					48.76	16.10	6.55
21.0	1,312	175					64.63	21.75	8.85
24.0	1,500	200					86.25	28.68	11.54
30.0	1,875	250						45.21	17.84
36.0	2,250	300						64.53	25.76
42.0	2,625	350							34.96
48.0	3,000	400							44.85
60.0	3,375	450							57.50
75.0	3,750	500							70.84

TABLE LXII—Continued

Table for determining combined efficiency of pump and motor.

Motor Efficiency	Pump Efficiency					
	75	65	50	45	40	35
70	52	46	35	32	28	24
75	56	48	38	34	30	26
80	60	52	40	36	32	28
85	64	56	43	38	34	30

Theoretical and practical suction limit.

Altitude	Theoretical	Practical
Sea level	33.95	25
1,320 ft. above	32.38	24
2,640 ft. above	30.79	23
3,960 ft. above	29.24	21
5,280 ft. above	27.76	20
10,560 ft. above	22.82	17

Reactive Coils.—This term describes coils introduced into a circuit to produce a certain reactance. They are also known as reactors. They are used to limit short-circuiting currents. Reactors are usually designed for a high temperature rise, and should be treated as sources of heat. When used in connection with lightning arresters they are often spoken of as "choke coils."

Rectifiers.—The mercury-arc rectifier is the one most used for arc lamp operation and is very common in motion picture theaters. Other types are the electrolytic and rotary. The mercury-arc type is also much used for storage battery work in connection with automobile charging. It is usually fed through autotransformers, but sometimes through constant current transformers, and then delivers a constant current. Most rectifiers are operated on single-phase circuits, but they can be arranged for two-phase and three-phase circuits and operate more advantageously. They may also be operated in parallel. Rectifiers designed for 40 to 50 amperes usually have glass tubes, but if larger capacities are required, the tubes are metallic. The power factor is ordinarily about 0.90. The drop in voltage is always about the same, hence

the lower the voltage the lower the efficiency. The average efficiency is about 75 or 80 per cent. If the vacuum is good, shaking the tube will cause a metallic sound; if tube is dirty on inside, the vacuum is usually poor.

Reciprocals of Numbers.—The reciprocal of any number is equal to 1 divided by that number. The reciprocal gives by multiplication what the number would give by division, and vice versa. The principle involved is made use of in many formulae and is much used to facilitate calculations. The reciprocals have been given only for whole numbers and up to the number 100. The reciprocal of any number larger or smaller may, however, easily be found by adding a decimal point to the reciprocal for each number added to its integer or subtracting one for each integer taken from the whole number. The larger the number, the more decimal places the reciprocal will contain. The smaller the number, the greater will be its reciprocal.

Thus the reciprocal of	7.3	0.13698
	73	0.013698
	730	0.0013698
	7300	0.00013698
	0.73	1.3698
	0.073	13.698
	0.0073	136.98

To find the reciprocal of a number trace along until this number is found. Thus the reciprocal of 21.7 is 0.04608.

To find the number pertaining to any reciprocal find the reciprocal and take the number. Thus the whole number of which 0.2710 is the reciprocal is 36.9.

TABLE LXIII

Reciprocals of Numbers

0	0	1	2	3	4	5	6	7	8	9
0.....	.0	10.000	5.000	3.333	2.500	2.000	1.667	1.4286	1.250	1.111
1.....	1.000	.90909	.83333	.76923	.71429	.66667	.62500	.58823	.55555	.52631
2.....	.50000	.47619	.45456	.43478	.41666	.40000	.38461	.37037	.35714	.34483
3.....	.33333	.32258	.31250	.30303	.29412	.28571	.27778	.27027	.26316	.25641
4.....	.25000	.24390	.23809	.23256	.22727	.22222	.21739	.21276	.20833	.20408
5.....	.20000	.19608	.19231	.18868	.18518	.18182	.17857	.17544	.17214	.16949
6.....	.16667	.16393	.16129	.15873	.15625	.15384	.15151	.14925	.14706	.14493
7.....	.14285	.14084	.13889	.13699	.13513	.13333	.13158	.12987	.12820	.12658
8.....	.12500	.12345	.12195	.12048	.11904	.11764	.11628	.11494	.11364	.11236
9.....	.11111	.10989	.10869	.10753	.10638	.10526	.10417	.10309	.10204	.10101
10.....	.10000	.09901	.09804	.09709	.09615	.09524	.09434	.09346	.09259	.09174
11.....	.09090	.09009	.08929	.08849	.08772	.08696	.08621	.08547	.08475	.08403
12.....	.08333	.08264	.08196	.08130	.08064	.08000	.07937	.07874	.07812	.07752
13.....	.07692	.07633	.07576	.07519	.07463	.07407	.07353	.07299	.07246	.07194
14.....	.07143	.07092	.07042	.06993	.06944	.06896	.06849	.06803	.06757	.06711
15.....	.06667	.06622	.06579	.06536	.06493	.06452	.06410	.06369	.06329	.06289
16.....	.06250	.06211	.06173	.06135	.060976	.06060	.06024	.05988	.05952	.05917
17.....	.05882	.05848	.05814	.05780	.057471	.05714	.05682	.05650	.05618	.05587
18.....	.05556	.05525	.05494	.05464	.054348	.05404	.05376	.05348	.05319	.05291
19.....	.05263	.05236	.05208	.05181	.05154	.05128	.05102	.05076	.05050	.05025
20.....	.05000	.04975	.04950	.04926	.04902	.04878	.04854	.04831	.04808	.04785
21.....	.04762	.04739	.04717	.04695	.04673	.04651	.04630	.04608	.04587	.04566
22.....	.04545	.04525	.04504	.04484	.04464	.04444	.04425	.04405	.04386	.04367
23.....	.04348	.04329	.04310	.04292	.04273	.04255	.04237	.04219	.04202	.04184
24.....	.04167	.04149	.04132	.04115	.04098	.04081	.04065	.04049	.04932	.04016

TABLE LXIII—Continued

Reciprocals of Numbers

0	0	1	2	3	4	5	6	7	8	9
25.....	.04000	.03984	.03968	.03953	.03937	.03922	.03906	.03891	.03876	.03861
26.....	.03846	.03831	.03817	.03802	.03788	.03773	.03759	.03745	.03731	.03717
27.....	.03704	.03690	.03676	.03663	.03650	.03636	.03623	.03610	.03597	.03584
28.....	.03571	.03559	.03546	.03534	.03521	.03509	.03496	.03484	.03472	.03460
29.....	.03448	.03436	.03425	.03413	.03401	.03389	.03378	.03367	.03356	.03344
30.....	.03333	.03322	.03311	.03300	.03289	.03279	.03268	.03257	.03247	.03236
31.....	.03226	.03215	.03205	.03195	.03185	.03175	.03165	.03155	.03145	.03135
32.....	.03125	.03115	.03105	.03096	.03086	.03077	.03067	.03058	.03049	.03039
33.....	.03030	.03021	.03012	.03003	.02994	.02985	.02976	.02967	.02959	.02950
34.....	.02941	.02933	.02924	.02915	.02907	.02899	.02890	.02881	.02874	.02865
35.....	.02857	.02849	.02841	.02833	.02825	.02817	.02809	.02801	.02793	.02785
36.....	.02778	.02770	.02762	.02755	.02747	.02740	.02732	.02725	.02717	.02710
37.....	.02703	.02695	.02688	.02681	.02674	.02667	.02660	.02652	.02645	.02638
38.....	.02632	.02625	.02618	.02611	.02604	.02597	.02591	.02584	.02577	.02571
39.....	.02564	.02557	.02551	.02544	.02538	.02532	.02525	.02519	.02513	.02506
40.....	.02500	.02494	.02488	.02481	.02475	.02469	.02463	.02457	.02451	.02445
41.....	.02439	.02433	.02427	.02421	.02415	.02410	.02404	.02398	.02392	.02387
42.....	.02381	.02375	.02369	.02364	.02358	.02353	.02347	.02342	.02336	.02331
43.....	.02326	.02320	.02315	.02309	.02304	.02299	.02294	.02288	.02283	.02278
44.....	.02273	.02268	.02262	.02257	.02252	.02247	.02242	.02237	.02232	.02227
45.....	.02222	.02217	.02212	.02207	.02203	.02198	.02193	.02188	.02183	.02179
46.....	.02174	.02169	.02164	.02160	.02155	.02150	.02146	.02141	.02137	.02132
47.....	.02113	.02123	.02119	.02114	.02110	.02105	.02100	.02096	.02092	.02087
48.....	.02083	.02079	.02075	.02070	.02066	.02062	.02058	.02053	.02049	.02045
49.....	.02041	.02037	.02032	.02028	.02024	.02020	.02016	.02012	.02008	.02004

TABLE LXIII—Continued

Reciprocals of Numbers

0	0	1	2	3	4	5	6	7	8	9
50.....	.02000	.01996	.01992	.01988	.01984	.01980	.01976	.01972	.01968	.01965
51.....	.01961	.01956	.01953	.01949	.01945	.01942	.01938	.01934	.01930	.01927
52.....	.01923	.01919	.01916	.01912	.01908	.01905	.01901	.01897	.01894	.01890
53.....	.01887	.01883	.01880	.01876	.01873	.01869	.01866	.01862	.01859	.01855
54.....	.01852	.01848	.01845	.01842	.01838	.01835	.01832	.01828	.01825	.01821
55.....	.01818	.01815	.01812	.01808	.01805	.01802	.01798	.01795	.01792	.01789
56.....	.01786	.01782	.01779	.01777	.01773	.01770	.01767	.01764	.01761	.01757
57.....	.01754	.01751	.01748	.01745	.01742	.01739	.01736	.01733	.01730	.01727
58.....	.01724	.01721	.01718	.01715	.01712	.01709	.01706	.01704	.01700	.01698
59.....	.01695	.01692	.01689	.01686	.01683	.01681	.01678	.01675	.01672	.01669
60.....	.01667	.01664	.01661	.01658	.01656	.01653	.01650	.01647	.01645	.01642
61.....	.01639	.01637	.01634	.01631	.01628	.01626	.01623	.01621	.01618	.01615
62.....	.01613	.01610	.01607	.01605	.01603	.01600	.01597	.01595	.01592	.01590
63.....	.01587	.01585	.01582	.01580	.01577	.01575	.01572	.01570	.01567	.01565
64.....	.01562	.01560	.01558	.01565	.01553	.01550	.01548	.01546	.01543	.01541
65.....	.01538	.01536	.01534	.01531	.01529	.01527	.01524	.01522	.01520	.01517
66.....	.01515	.01513	.01511	.01508	.01506	.01504	.01501	.01499	.01497	.01495
67.....	.01492	.01490	.01488	.01485	.01484	.01481	.01479	.01477	.01475	.01473
68.....	.01471	.01468	.01466	.01464	.01462	.01460	.01458	.01456	.01453	.01451
69.....	.01449	.01447	.01445	.01443	.01441	.01439	.01437	.01435	.01433	.01431
70.....	.01429	.01426	.01424	.01422	.01420	.01418	.01416	.01414	.01412	.01410
71.....	.01408	.01406	.01404	.01402	.01400	.01399	.01397	.01395	.01393	.01391
72.....	.01389	.01387	.01385	.01383	.01381	.01379	.01377	.01375	.01374	.01372
73.....	.01370	.01368	.01366	.01364	.01362	.01360	.01359	.01357	.01355	.01353
74.....	.01351	.01349	.01347	.01346	.01344	.01342	.01340	.01339	.01337	.01335

TABLE LXIII—Continued

Reciprocals of Numbers

0	0	1	2	3	4	5	6	7	8	9
75.....	.01333	.01332	.01330	.01328	.01326	.01324	.01323	.01321	.01319	.01317
76.....	.01316	.01314	.01312	.01310	.01309	.01307	.01305	.01304	.01302	.01300
77.....	.01299	.01297	.01295	.01293	.01292	.01290	.01289	.01287	.01285	.01284
78.....	.01282	.01280	.01279	.01277	.01275	.01274	.01272	.01271	.01269	.01267
79.....	.01266	.01264	.01263	.01261	.01259	.01258	.01256	.01255	.01253	.01252
80.....	.01250	.01248	.01247	.01245	.01244	.01242	.01241	.01239	.01238	.01236
81.....	.01234	.01233	.01231	.01230	.01228	.01227	.01225	.01224	.01222	.01221
82.....	.01219	.01218	.01216	.01215	.01214	.01212	.01211	.01209	.01208	.01206
83.....	.01205	.01203	.01202	.01200	.01199	.01198	.01196	.01195	.01193	.01192
84.....	.01190	.01189	.01188	.01186	.01185	.01183	.01182	.01181	.01179	.01178
85.....	.01176	.01175	.01174	.01172	.01171	.01170	.01168	.01167	.01165	.01164
86.....	.01163	.01161	.01160	.01159	.01157	.01156	.01155	.01153	.01152	.01151
87.....	.01149	.01148	.01147	.01146	.01144	.01143	.01142	.01140	.01139	.01138
88.....	.01136	.01135	.01134	.01132	.01131	.01130	.01129	.01127	.01126	.01125
89.....	.01124	.01122	.01121	.01120	.01119	.01117	.01116	.01115	.01114	.01112
90.....	.01111	.01110	.01109	.01107	.01106	.01105	.01104	.01102	.01101	.01100
91.....	.01099	.01098	.01096	.01095	.01094	.01093	.01092	.01090	.01089	.01088
92.....	.01087	.01086	.01085	.01083	.01082	.01081	.01080	.01079	.01078	.01076
93.....	.01075	.01074	.01073	.01072	.01071	.01069	.01068	.01067	.01066	.01065
94.....	.01064	.01063	.01062	.01060	.01059	.01058	.01057	.01056	.01055	.01054
95.....	.01053	.01051	.01050	.01049	.01048	.01047	.01046	.01045	.01044	.01043
96.....	.01042	.01041	.01039	.01038	.01037	.01036	.01035	.01034	.01033	.01032
97.....	.01031	.01030	.01028	.01028	.01027	.01026	.01025	.01023	.01022	.01021
98.....	.01020	.01019	.01018	.01017	.01016	.01015	.01014	.01013	.01012	.01011
99.....	.01010	.01009	.01008	.01007	.01006	.01005	.01004	.01003	.01002	.01001
100.....	.01000	.00999	.00998	.00997	.00996	.00995	.00994	.00993	.00992	.00991

Reflectors.—Perfect prismatic glass makes the very best reflector. The following table gives approximately the percentage of light reflected by various materials:

TABLE LXIV

	Per Cent Light Reflected
Well polished silver	92
Silvered mirror	70 to 90
Highly polished brass	70 to 85
Mirror backed with amalgam	70
Well polished copper	60 to 70
Well polished steel	60
Burnished copper	40 to 50
Chrome yellow paper	60
Orange paper	50
Yellow paper or painted wall	40
Pink paper	35
Blue wall paper	25
Emerald green paper	18
Dark brown paper	13
Vermilion paper	12
Bluish green paper	12
Cobalt blue paper	12
Deep chocolate colored paper	4
Black cloth	1.2
Black velvet	0.4

Refrigeration.—Refrigeration by machinery is much more reliable, effective and cleanly than that produced by the use of ice. Electric power compares favorably with steam power in large installations, but more especially so in the smaller plants. Its main advantages are: lower first cost, less space required; less attendance and operation; can be made automatic. For direct current, compound-wound motors are preferable, and where variable speed is desired, the speed control should be by means of field regulation. For alternating current, the squirrel cage type of arma-

ture may be used, but if speed control is desired, a wound armature should be provided. The latter is much preferable for automatic control. The horsepower required for refrigeration can be determined by means of the curves in Figure 17, due to Westinghouse Electric & Mfg. Co. The upper curve is for compressors of 50 H.P. and smaller; the lower curve

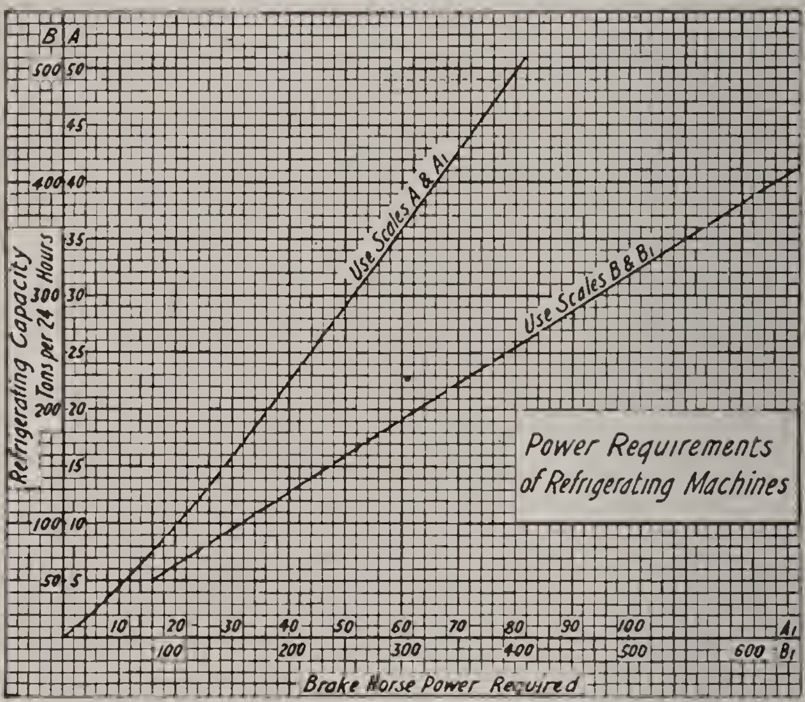


Figure 17.

for larger machines. For example: a 30-ton compressor requires a 52 H.P. motor; a 300-ton compressor requires a 470 H.P. motor. When the ice-making capacity of compressor is given, the motor H.P. required will in general be about double the figure given in the curve.

Refrigerators.—All refrigerators are at times very damp. As long as they are kept cold, ice forms, and as soon as they are empty the ice melts and all parts become wet. No very bright illumination is required, and in many of them workmen are required to get

along with lanterns. Weatherproof construction is preferable to conduit in all places except where heavy coatings of ice form on the wires. This frost is scraped off from time to time, and open wires are likely to be torn loose. Porcelain sockets break easily and should not be used. Circuits should not enter or leave too close to entrances; the meeting of the cold and warm air at such places cause the deposit of much moisture. Lamps are usually placed only in runways, and in large refrigerators the circuits are apt to be long. In some of the large refrigerators watchmen are regularly making rounds; in such places three-way switches at doors are useful. Keep cut-outs and switches outside of damp rooms and avoid the use of the common fiber-lined brass shell socket.

Residence Wiring.—As a general rule a total wattage capacity of about $\frac{1}{2}$ watt per sq. ft. should be provided for the whole building, including cellar and attic. If these latter are not to be illuminated, 1 watt per sq. ft. will be ample for the balance of house. The best place for service switch and meters is in the basement. Select a location easily accessible to meter readers. If not too much economy is necessary, let two circuits enter each room that contains more than one outlet. Place all switches at doors where room is most likely to be entered, and if there are two entrances two-way switches will be a great convenience. In some elaborate residences circuits are sometimes so arranged that lights in all rooms may be thrown on by a master switch, even if turned off in rooms. This is useful as burglar protection and also in case of fires. A measure of protection against intruders can be obtained by placing lights above doors so that an intruder must show himself in the light before he can enter a room. The bright light will prevent him from seeing what is inside the door.

Attics.—No part of residence requires light more than the attic. The use of matches is exceedingly dangerous in such places. Run wires where they will not be molested.

Bathroom.—A center light in a bathroom is an abomination. Place a light at each side of shaving mirror if practicable, but locate them so that person in tub cannot reach socket. An outlet for heater will be a great convenience. If possible place or shade lamps so they will not cast shadows of persons on window. Place a switch at door. If expense is no object, inverted lighting will be very useful.

Basement.—The wiring of the basement depends upon the use to which it may be put. Two or three-way switches, one at each entrance, will be very convenient. Plenty of light will be an inducement for servants to keep basement cleaner than the average. Provisions should be made for motors to operate ice cream freezers, washing machines, mangels, or vacuum cleaning motors. It is much preferable to place the motor for this purpose in the basement rather than to bother with portable machines. Fan motor outlets will assist in drying clothes. If part of basement is used as laundry and likely to be damp, use weather-proof construction and avoid placing sockets where one standing on wet floor will be likely to touch them. Provide outlet for flatiron.

Bedrooms.—A center fixture should never be installed in a bedroom unless it is intended also as a sort of living room. Lights should be arranged to suit the various positions in which a bed can advantageously be placed, and so that one can use the light for reading in bed or make easy connections for heating pads. Special outlets along baseboard for flatiron heaters, sewing machine motors, etc., will be found very useful. One light on each side of dresser mirror is a great convenience. Avoid placing lights so that

they will cast shadows of occupants on windows. For protection against burglars, a switch by which lights in other rooms may be turned on is very effectual. See "Modern Wiring Diagrams and Descriptions" for circuits. Such a switch might be placed in each bedroom. Inverted lighting is very useful if only one light can be installed and if ceilings are light enough.

Cellars.—A cellar is usually damp, and weatherproof construction should be used. Keep switch outside at door.

Closets.—The use of matches in closets is very dangerous and will be entirely eliminated by good illumination. Place a light at ceiling and control by switch if closet is small. In large closets a pendant light may be advisable, but there is usually too much chance of clothing coming in contact with it and the cord.

Dining Rooms.—Beam lighting is used to some extent in dining rooms. Special illumination of buffet and china closet is also often practiced. Small lamps are used for the latter and should be located to show off cut glass, etc., to the best advantage. It is well to study the effect of such lights carefully before finally locating them. To show off silverware, fine table linen, etc., to the best advantage it is advisable to concentrate a strong light upon the table and leave balance of room somewhat dark. Side outlets for fan motors, and floor sockets for chafing dishes, are very useful. The low hanging fixtures often seen in dining rooms should not be recommended. They will soon become obnoxious.

Halls.—Halls ordinarily require only a perfunctory illumination unless a showy appearance is desired. These lights are often combined with stair lights and fitted with two or three-way switches. Place switch for hall light close to the door.

Ice Boxes or Chambers.—A light placed opposite door will be very useful.

Kitchen.—If kitchen walls are of light color, a center light will give good illumination. With dark colored walls a light should be placed over sink and near range, but a little to one side, so as to avoid the cooking fumes as much as possible. A small motor to drive steam out will be of great use. Ozonators to destroy odors will also be much appreciated. As ironing is often done in the kitchen, an outlet for irons should always be provided. If electric cooking is indulged in this must be provided for.

Laundry.—There should be a light directly over wash tubs and another arranged to be directly over ironing board. If clothes are dried in laundry a fan or ventilating motor will be of great service. Provisions should be made for washing machine motors, mangels and flatiron. Locate sockets so persons will not be likely to touch them while standing on wet floor.

Lavatory.—One light controlled by door-switch is very useful here.

Library.—Inverted lighting of sufficient c.p. to allow the reading of titles of books in cases is the best means of illumination here. In addition to this there should be outlets for reading lamps and brackets conveniently located on walls to give a brighter light for those that need it. A direct light with strong reflector under inverted light is useful for reading purposes.

Nursery.—The lighting of the nursery should be ample, but precautions should be taken to guard against the possibility of outlets being short circuited by children. Avoid placing sockets within easy reach. Electric toys should be confined to battery current, or a low-voltage transformer, to which children have no access, might be used. The lighting voltage is too dangerous for them. Control all lights by switches and keep them high.

Pantry.—Provide bright illumination to show up dust and dirt and induce cleanliness.

Parlor.—The illumination of the parlor is usually effected by means of quite elaborate chandeliers. Outlets for piano and reading lamps should be provided. The center light does not illuminate pictures very well, and for this reason inverted lighting is often useful. Really good pictures, however, deserve special illumination.

Porch.—A light should be arranged close to main entrance and so located as to reveal features of persons applying for admission without making the party inside of house visible. The light should be controlled by a switch inside and should be out of reach from the outside. If porch is to be enclosed, other outlets for lamps or fan motors will be useful, but they should be arranged at ceiling so as to avoid moisture. Use no fiber lined sockets outside.

Resuscitation from Electric Shock.—Rules recommended by commission on resuscitation from electric shock, representing The American Medical Association, The National Electric Light Association, The American Institute of Electrical Engineers. Issued and copyrighted by National Electric Light Association. Reprinted by permission.

Follow these instructions even if victim appears dead.

I. Immediately Break the Circuit.—With a single quick motion, free the victim from the current. Use any *dry non-conductor* (clothing, rope, board) to move either the victim or the wire. Beware of using metal or any moist material. While freeing the victim from the live conductor have every effort also made to shut off the current quickly.

II. Instantly Attend to the Victim's Breathing.—(1) As soon as the victim is clear of the conductor, rapidly feel with your finger in his mouth and throat

and remove any foreign body (tobacco, false teeth, etc.). Then *begin artificial respiration at once.* Do not stop to loosen the victim's clothing now; *every moment of delay is serious.* Proceed as follows:

a. Lay the subject on his belly, with arms extended as straightforward as possible and with face to one side, so that nose and mouth are free for breathing.

Figure 18. Inspiration—Pressure Off.

See Figure 18. Let an assistant draw forward the subject's tongue.

b. Kneel straddling the subject's thighs and facing his head; rest the palms of your hands on the loins (on the muscles of the small of the back), with fingers spread over the lowest ribs, as in Figure 18.

c. With arms held straight, swing forward slowly so that the weight of your body is gradually, but *not violently,* brought to bear upon the subject. See Figure 19. This act should take from two to three seconds.

Immediately swing backward so as to remove the

pressure, thus returning to the position shown in Figure 18.

d. Repeat deliberately twelve to fifteen times a minute the swinging forward and back—a complete respiration in four or five seconds.

e. As soon as this artificial respiration has been started, and while it is being continued, an assistant

Figure 19. Expiration—Pressure On.

should loosen any tight clothing about the subject's neck, chest or waist.

(2) Continue the artificial respiration (if necessary, at least an hour), *without interruption*, until natural breathing is restored, or until a physician arrives. If natural breathing stops after being restored, use artificial respiration again.

(3) *Do not give any liquid by mouth until the subject is fully conscious.*

(4) Give the subject fresh air, but keep him warm.

III. Send for Nearest Doctor as Soon as Accident Is Discovered.

Ropes.—

TABLE LXV

Standard Iron Hoisting Rope, 6 Strands—19 Wires to the Strand—1 Hemp Rope. American Steel & Wire Co.

Diameter in Inches	Circumference in Inches	Approximate Weight Per Ft. in Pounds	Approximate Strength in Tons of 2,000 Lbs.	Proper Working Load in Tons	Diameter of Drum or Sheave Advised in Feet
$2\frac{3}{4}$	$8\frac{5}{8}$	11.95	111.0	22.2	17
$2\frac{1}{2}$	$7\frac{7}{8}$	9.85	92.0	18.4	15
$2\frac{1}{4}$	$7\frac{1}{8}$	8.00	72.0	14.4	14
2	$6\frac{1}{4}$	6.30	55.0	11.0	12
$1\frac{7}{8}$	$5\frac{3}{4}$	5.55	50.0	10.0	12
$1\frac{3}{4}$	$5\frac{1}{2}$	4.85	44.0	8.8	11
$1\frac{5}{8}$	5	4.15	38.0	7.6	10
$1\frac{1}{2}$	$4\frac{3}{4}$	3.55	33.0	6.6	9
$1\frac{3}{8}$	$4\frac{1}{4}$	3.00	28.0	5.6	8.5
$1\frac{1}{4}$	4	2.45	22.8	4.56	7.5
$1\frac{1}{8}$	$3\frac{1}{2}$	2.00	18.6	3.72	7.0
1	3	1.58	14.5	2.90	6.0
$\frac{7}{8}$	$2\frac{3}{4}$	1.20	11.8	2.36	5.5
$\frac{3}{4}$	$2\frac{1}{4}$	0.89	8.5	1.70	4.5
$\frac{5}{8}$	2	0.62	6.0	1.20	4.0
$\frac{9}{16}$	$1\frac{3}{4}$	0.50	4.7	0.94	3.5
$\frac{1}{2}$	$1\frac{1}{2}$	0.39	3.9	0.78	3.0
$\frac{7}{16}$	$1\frac{1}{4}$	0.30	2.9	0.58	2.75
$\frac{3}{8}$	$1\frac{1}{8}$	0.22	2.4	0.48	2.25
$\frac{5}{16}$	1	0.15	1.5	0.30	2.00
$\frac{1}{4}$	$\frac{3}{4}$	0.10	1.1	0.22	1.50

For better grades of rope smaller sheaves are advised.

Manila Rope.

Diameter	Circumference	Ultimate Strength	Pounds Per Foot	Diameter	Circumference	Ultimate Strength	Pounds Per Foot
½	1½	2,000	0.09	1⅜	4⅛	13,500	0.65
⅝	2	3,250	0.14	1½	4½	15,000	0.77
¾	2¼	4,000	0.20	1⅝	4⅞	18,200	0.90
⅞	2⅝	6,000	0.27	1¾	5¼	21,700	1.05
1	3	7,000	0.35	2	6	25,000	1.40
1⅛	3⅜	9,300	0.45	2¼	6¾	32,000	1.75
1¼	3¾	10,000	0.55	2½	7½	40,000	2.15

Splicing of Manila Rope.—The successive operations for making a common or English splice in a 1¾-inch 4-strand rope is as follows:

1. Tie a piece of twine, 9 and 10, *A*, Figure 20, around the rope to be spliced, about six feet from each end. Then unlay the strands of each end back to the twine.

2. Put the ropes together and twist each corresponding pair of strands loosely, to keep them from being tangled, as shown at *A*.

3. The twine 10 is now cut, and the strand 8 unlaid and strand 7 carefully laid in its place for a distance of four and a half feet from the junction.

4. The strand 6 is next unlaid about one and a half feet and strand 5 laid in its place.

5. The ends of the cores are now cut off so they just meet.

6. Unlay strand 1 four and a half feet, laying strand 2 in its place.

7. Unlay strand 3 one and a half feet, laying in strand 4.

8. Cut all the strands off to a length of about twenty inches, for convenience in manipulation. The rope now assumes the form shown in *B*, with the meeting point of the strands three feet apart.

Each pair of strands is now successively subjected to the following operations:

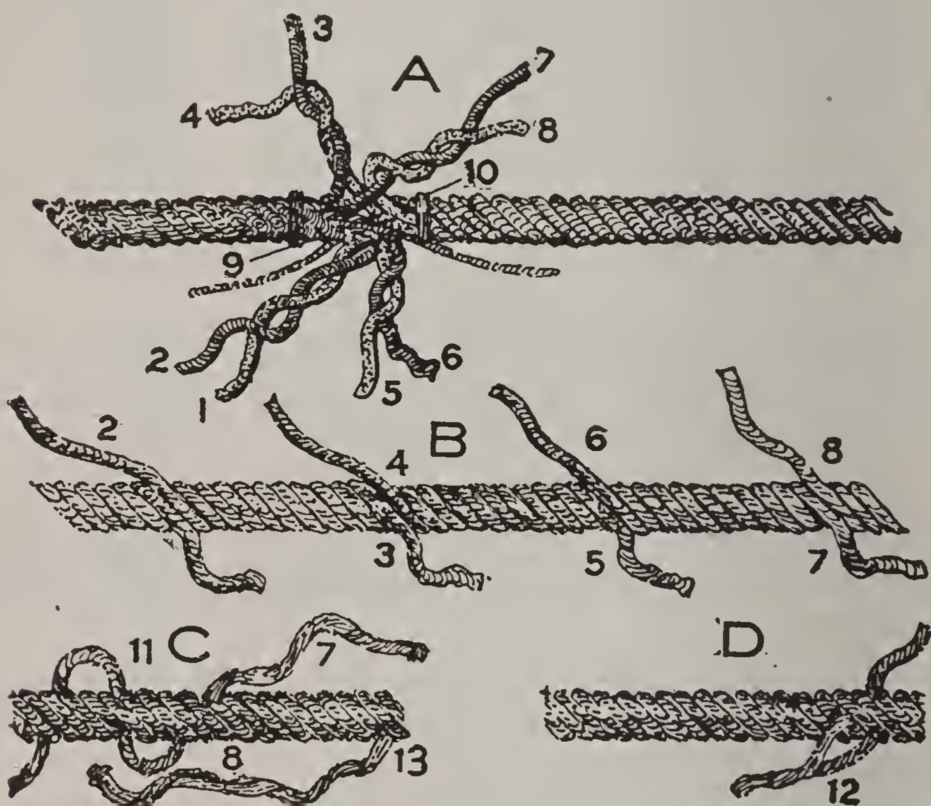


Figure 20.—Method of Splicing Ropes.

9. From the point of meeting of the strands 8 and 7 unlay each one three turns; split both the strand 8 and the strand 7 in halves, as far back as they are now unlaid, and the end of each half strand "whipped" with a small piece of twine.

10. The half of the strand 7 is now laid in three turns, and the half of 8 also laid in three turns. The half strands now meet and are tied in a simple

knot 11, *C*, making the rope at this point its original size.

11. The rope is now opened with a marlinspike, and the half strand of 7 worked around the half

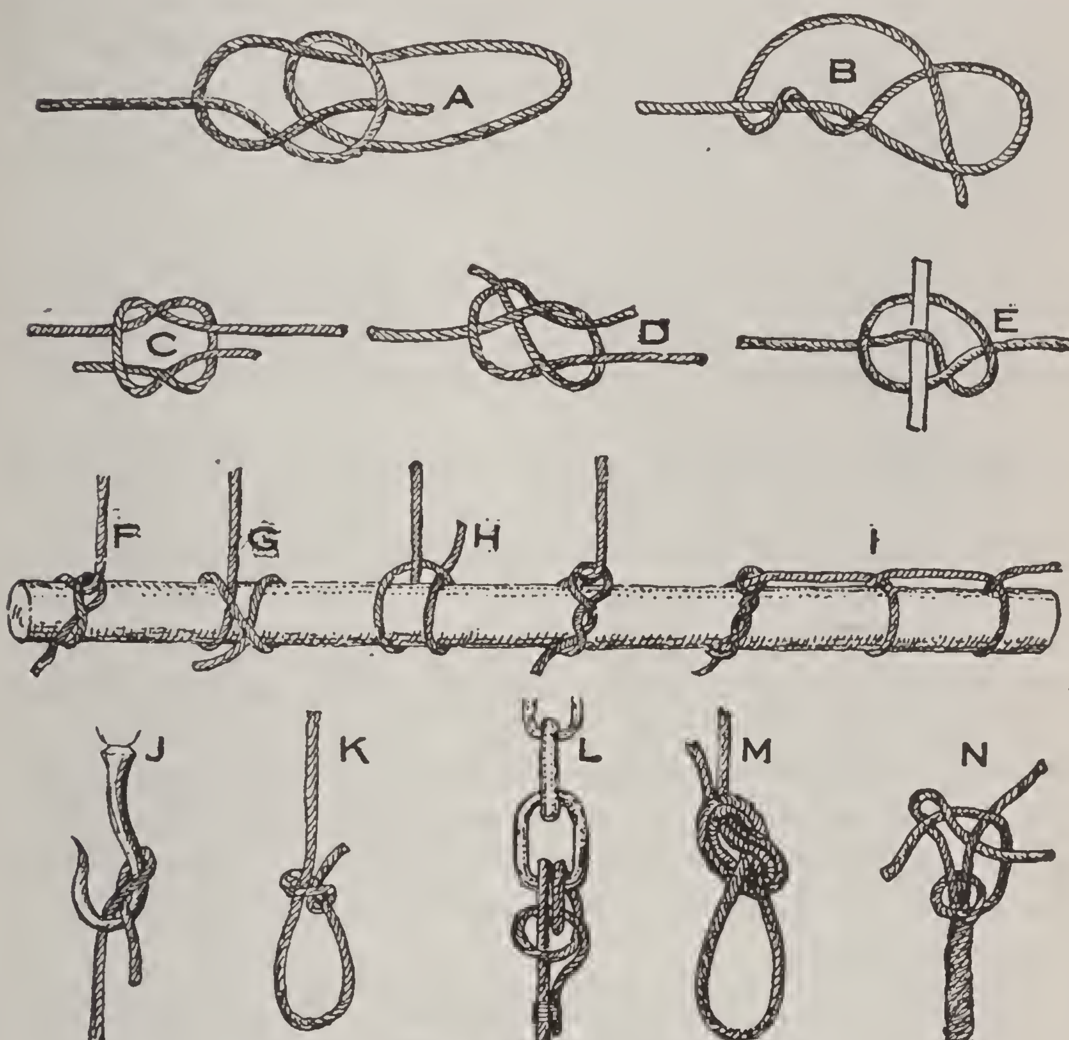


Figure 21.—Methods of Tieing Knots.

strand of 8 by passing the end of the half strand through the rope, as shown, drawn taut, and again worked around this half strand until it reaches the half strand 13 that was not laid in. This half strand 13 is now split, and the half strand 7 drawn through the opening thus made, and then tucked under the two adjacent strands, as shown in *D*.

12. The other half of the strand 8 is now wound around the other half strand 7 in the same way. After each pair of strands has been treated in this manner, the ends are cut off at 12, leaving them about four inches long. After a few days' wear they will draw into the body of the rope or wear off, so that the locality of the splice can scarcely be detected.

Figure 21 shows specimens of knots frequently used.

A, Bowline; *B*, Stevedore knot; *C*, Reef knot; *D*. Weavers knot; *E*, Boat knot; *F*, Half hitch; *G*, Timber hitch; *H*, Clove hitch; *I*, Timber and half hitch; *J*, Blackwall hitch; *K*, Common noose; *L*, Fishermen's bend; *M*, Common knot; *N*, Turks head.

Saloons.—In small saloons not much illumination is required. Where there is any pretense of importance, however, there is always some back-bar lighting, and this may often furnish the whole illumination. Special outlets for cash registers and hot water heaters should be provided. Nearly every saloon sooner or later provides a beer pump. In pretentious saloons a very elaborate illumination is often striven for. In case wine rooms, or other private places fitted with glass partitions, are to be illuminated the lights should be so placed that they will not cast shadows of occupants on glass.

Schools.—In large cities schools are often classed as assembly halls and special rules for wiring are made. There should be emergency lighting. A stereopticon outlet is a common requirement.

Screws.—Formulae for wood screws. N = number; D = diameter.

$$D = (N \times 0.01325) + 0.056$$

$$N = \frac{D - 0.056}{0.01325}$$

TABLE LXVI

Dimensions of Iron Screws (Approximate).

Trade Number	Diameter in Fractions	Nearest B. & S. Gauge	Greatest Length Obtainable
0	7/128	15	3/8
1	9/128	14	1/2
2	5/64	12	7/8
3	3/32	11	1 1/2
4	7/64	9	1 1/2
5	4/32	8	2 1/2
6	17/128	7	3
7	19/128	7	3
8	5/32	6	4
9	11/64	5	4
10	12/64	5	4
11	13/64	4	4
12	27/128	4	6
13	29/128	3	6
14	15/64	3	6
15	1/4	2	6
16	17/64	2	6
17	9/32	1	6
18	19/64	1	6

Service Entrance.—The service wires should be protected by fuses as close as possible to where they enter the building. There should be a service switch, and it and the fuses should be accessible.

Shelving.—To illuminate shelving properly is a troublesome matter. Portable lamps are essential, but these introduce an appreciable fire hazard. It is best to suspend lamps from ceiling by reinforced cord, and fit each lamp with a substantial guard. It is usually necessary to have good light close to the floor, but this can be had by keeping lamps about 6½ feet above floor. If shelves are deep and contain dark-

colored materials carrying indistinct numbers, attachments to these cords will often be necessary. Where lights are not constantly in use, three-way ceiling switches will be very useful and economical. Provide each group of lamps commonly used together with its own switch.

Show Windows.—In the best form of show-window lighting the lamps are always entirely hidden. Very brilliant effects are often striven for and the gas-filled mazda lamp is in great favor. Where there is bright illumination on the street in front, even greater illumination is required within. The object is, not only to make things visible, but to attract attention, and for this purpose the very brightest and whitest light is necessary. Most show windows are lighted from the top by reflectors, but in some cases an illumination from the bottom up must also be provided. In some cases the object is to show the lights and call attention to the fact that they are there. For this purpose small lamps, well frosted, are preferable. If they are too bright they will blind people to the objects in window. In some cases 32 c.p. lamps have been thickly studded over the whole ceiling of window. Time switches are much used for show-window lighting and enable one to keep his windows illuminated for advertising purposes after the store is closed. Fan motor outlets are very useful for winter to keep windows clear of frost. Place no wires near glass where water is liable to run down.

Signs, Electric.—Signs should be wired with the two sides independent so as to enable flasher to be used. Small lamps of low intrinsic brilliancy are preferable. Letters should be glossy white and kept clean. The following table gives dimensions and numbers of sockets of stock letters made by the Federal Electric Co. of Chicago, which may serve as a general guide to present practice.

TABLE LXVII

	10 Inch Letters		14 Inch Letters		16 Inch Letters 4 Lamp High		16 Inch Letters 5 Lamp High		24 Inch Letters	
	Sockets	Width	Sockets	Width	Sockets	Width	Sockets	Width	Sockets	Width
A	8	10	8	12½	8	15½	10	15½	11	21
B	10	10	10	12½	11	15½	13	15½	13	21
C	7	10	7	12½	7	15½	8	15½	8	21
D	8	10	8	12½	9	15½	11	15½	11	21
E	9	10	9	12½	9	15½	10	15½	13	21
F	7	10	7	12½	7	15½	8	15½	10	21
G	8	10	8	12½	8	15½	9	15½	11	21
H	9	10	9	12½	9	15½	11	15½	12	21
I	4	5½	4	6	4	8	5	8	5	9
J	6	10	6	12½	6	15½	7	15½	7	21
K	8	10	8	12½	9	15½	11	15½	11	21
L	6	10	6	12½	6	15½	7	15½	8	21
M	13	12½	13	15½	13	19½	15	19½	17	25
N	10	10	10	15½	10	15½	13	15½	13	21
O	8	10	8	15½	9	15½	10	15½	10	21
P	8	10	8	15½	8	15½	10	15½	10	21
Q	9	10	10	15½	9	15½	10	15½	11	21
R	10	10	10	15½	10	15½	12	15½	12	21
S	8	10	8	15½	8	15½	10	15½	10	21
T	6	10	6	15½	6	15½	7	15½	8	21
U	8	10	8	15½	9	15½	10	15½	10	21
V	7	10	7	15½	7	15½	9	15½	9	21
W	12	12½	12	15½	13	19½	15	19½	15	25
X	8	10	8	15½	9	15½	9	15½	9	21
Y	6	10	6	15½	6	15½	7	15½	8	21
Z	8	10	8	15½	8	15½	9	15½	11	21
&	8	10	8	15½	9	15½	9	15½	10	21
1	4	10	4	15½	4	15½			5	21
2	9	10	8	15½	8	15½			11	21
3	9	10	7	15½	7	15½			9	21
4	7	10	7	15½	7	15½			11	21
5	10	10	10	15½	10	15½			12	21
6	9	10	8	15½	9	15½			11	21
7	6	10	6	15½	6	15½			8	21
8	11	10	11	15½	8	15½			10	21
9	9	10	8	15½	9	15½			11	21
$	8	10	8	15½	8	15½			8	21
				15½		15½				

The supporting cable is usually attached to the electric sign somewhat back of its outer end, and it may be assumed that the cable carries about 60 per cent of the weight of sign. With this assumption and

using a safety factor of 5, the strength of the cables necessary to support it can be found by the formula:

$$S = 5 \times .60 \times W \frac{\sqrt{H^2 + D^2}}{H}$$

where W = weight of sign; H = height of attachment to wall above sign, and D = the distance from attachment on sign to a point vertically under sign support.

Table LXVIII is calculated according to this formula (omitting W), and to find the proper cable to support a given sign it is but necessary to multiply number found at intersection of line pertaining to height of support and that pertaining to distance of sign attachment from wall, by the weight of sign. The result will give the breaking strain of the necessary cable.

TABLE LXVIII

Supports for Weight of Sign.

Distance from Wall to Attachment on Sign in Feet	Height of Cable Fastening Above Sign in Feet										
	3	4	5	6	8	10	12	14	16	18	20
4	5	4	4	3.6	3.4	3.2	3.0	3	3	3	3
5	6	5	4.2	3.7	3.5	3.3	3.2	3	3	3	3
6	7	5.4	5.0	4.2	3.8	3.5	3.4	3.2	3	3	3
7	8	6.0	5.1	4.7	4.0	3.7	3.5	3.4	3.3	3	3
8	8.6	6.8	5.7	5.0	4.2	4.0	3.6	3.5	3.4	3.3	3
10	10.5	8.1	6.9	6.0	5.0	4.4	3.9	3.8	3.6	3.4	3.3
12	12.4	9.4	7.8	6.7	5.4	4.6	4.3	4.0	3.7	3.5	3.4
14	14.6	11.1	9.0	7.8	6.0	5.2	4.8	4.1	4.0	3.9	3.7

SIDE GUYS FOR SIGNS

The wind pressure on the ordinary sign must be calculated on the basis of 20 lbs. per square foot and requires much better supports to withstand it than are necessary to support the weight of sign, although they are never so provided.

The table below has been calculated according to the same general formula as the one above. To find the proper size of cable for side guys, multiply the number of square feet in sign by number found where lines pertaining to the two fastenings of side guys cross.

TABLE LXIX

Distance of Attachment on Sign from Wall	Distance of Guy Attachment on Wall from Sign in Feet.									
	3	4	5	6	7	8	10	12	14	16
2	17	17	16	15	15	14	14	14	14	14
3	21	18	18	17	16	15	14	14	14	14
4	24	20	18	17	16	16	15	15	14	14
5	27	22	20	19	18	17	16	16	15	14
6	31	25	22	20	19	18	17	16	15	15
7	34	28	24	22	20	19	18	17	16	15
8	38	32	27	24	21	19	18	17	17	16
9	44	35	29	26	22	21	19	18	18	17
10	48	38	32	28	24	23	20	19	18	17
12	57	45	37	33	27	25	22	21	19	18

For signs hung at corners the distance of guy attachment on wall must be taken as the point at right angles to sign where the guy would strike wall if it were at right angles to sign.

TABLE LXX

Table showing approximate strength in pounds of Standard Steel Strand—American Steel & Wire Co.

Diameter in Inches	Approximate Strength	Diameter in Inches	Approximate Strength
$\frac{1}{2}$	8,500 lbs.	$\frac{7}{32}$	1,800 lbs.
$\frac{7}{16}$	6,500 lbs.	$\frac{3}{16}$	1,400 lbs.
$\frac{3}{8}$	5,000 lbs.	$\frac{5}{32}$	900 lbs.
$\frac{5}{16}$	3,800 lbs.	$\frac{1}{8}$	500 lbs.
$\frac{1}{4}$	2,300 lbs.	$\frac{3}{32}$	400 lbs.

Cable Supports for Signs Over Streets.—Signs of this kind are usually supported from steel cables swung across street, or other open place, from the tops of buildings or suitable poles. The table below gives the stresses caused by various loads per foot evenly distributed, and also for loads suspended from center. The arrangement of sign is usually such that neither case exactly applies, so that an approximate mean of the two must be taken. The calculations are for a 100-foot span and a sag of 4 feet.

TABLE LXXI

Diameter of Cable	Wt. per Foot	Approximate Strength	Stress Caused by Cable Alone	Distributed Load		Load in Center	
				Pounds	Stress	Pounds	Stress
$1\frac{3}{4}$	4.85	84,000	1,500	50	17,140	2,500	15,625
$1\frac{1}{2}$	3.55	60,000	1,109	30	10,484	1,500	9,375
$1\frac{1}{4}$	2.45	46,000	766	20	7,015	1,000	6,250
1	1.58	28,000	493	15	5,181	750	4,687
$\frac{7}{8}$	1.20	22,200	375	12	4,125	600	3,750
$\frac{3}{4}$	0.89	15,600	278	9	3,090	500	3,125

The above figures represent the maximum loads which should be suspended by such cables unless a greater sag is allowed, and do not take wind pressure into consideration. See "Side Guys."

The above figures are based on the following formulae used by American Steel and Wire Co.:

$S_1 = \frac{Wl^2}{8d}$ giving stress for evenly distributed load, and

$S_2 = \frac{Wl}{4d}$ for stress due to load in center.

S = stress on cable
W = weight per foot of cable and load if evenly distributed, or load in center
l = length of span
d = sag in feet.

To find total stress those due to cable and load must be added.

Slide Rule.—Figure 22 is an illustration of the ordinary slide rule. The numbers on the top, or *A*, scale, may be read naturally as 1, 2, 3, 4, etc., ending with the last figure 1 at the right, which would then be called 100, or these values may be considered increased or decreased to any extent by adding or prefixing the necessary number of ciphers. Thus if the 2 is called 20 or 200 the 3 would be called 30 or 300, etc. The same also holds true of the upper half of the slide, or *B* scale. The divisions between the main figures are of various dimensions, but serve only

Figure 22.—The Slide Rule.

to designate fractional values of the figures. The principle of operation can easiest be made clear by examples.

Multiplication.—Set the 1 on upper half of slide under one of the factors on scale *A*. Find the other factor on the slide and directly above it you have the product. Multiply 4 by 2. Setting the slide as directed we find 8. This same setting might be used to multiply 40 by 20, or 4000 by 2 or 200. We have but to note as we go along by how much we increased the value of either of the factors, and add the corresponding number of ciphers. Different settings could also be used for the same problem. Considerable practice is necessary before one can become really proficient in these calculations.

Division.—In division the above process is reversed. Place the divisor on the slide under the dividend on

scale A and the 1 on slide will be directly below the quotient.

Multiplication and Division Combined.—

Example: $\dfrac{7 \times 3 \times 4}{6}$

Set 1 on slide under 7, note product above 3; next set 1 on slide under this product and note product above 4. Now move slide back until 6 is under last product and find answer above 1.

Proportion.—By setting any number on B against any convenient number on A it can be seen that all other coinciding numbers are in the same proportion to each other. Hence any problem in direct proportion can be solved by simply setting the first term on B against the second on A; this being done, we shall find the last term directly above the third on B. Example: If 7 bushels of wheat cost \$13.00, how much will 23 bushels cost? Answer, \$42.71. In direct proportion all factors are either increasing or decreasing. If they are mixed it is termed Inverse Proportion. In order to solve a problem in inverse proportion we invert the slide, but continue to read A and B together. Example: If 9 men can do a piece of work in 17 days, how many days will 13 men require? Inverting the slide and setting the 9 on the left under 17 and bringing the runner over the 13 at the right at about the center of the scale, we find 11.8 as the answer.

Squaring Numbers and Extracting Square Roots.—When the slide is set even on all sides, the numbers in the scales A and B are the squares of those in C and D. Hence also those in the last named scales are the square roots of the upper. They must, however, be taken with the proper number of ciphers. The square of 2, for instance, is 4, that of 20 is 400

and that of 200 equals 40,000. In extracting square roots, if the number of digits is odd, 4, 400, etc., the root will be found directly under the number on left hand side of scale. If the number of digits is even, it will be found on right hand side, viz., square root of 40 equals 6.41.

Extracting Cube Root.—Set the runner on the number, the root of which is to be found, and shift the slide until the same number found under this number is also found under the index of the slide on the lower part *D*. According to location of runner either the right or left hand index must be used. Practice raising number to the third power; reversing this process will show method of extracting roots.

Sockets.—Nearly all lamps used in this country are fitted with the well-known Edison base. A few old installations equipped with the T. H. base still remain, but are usually equipped with adjusters to permit the use of Edison base lamps.

The standard sockets as recognized by the N. E. C. are given below:

Classification.—Sockets to be classed according to diameters of lamp bases, as Candelabra, Medium and Mogul. Base to be known respectively as ½ inch, 1 inch and 1½ inch nominal sizes, with ratings as specified in the following table:

		Ratings					
		Key			Keyless		
Class	Nominal Diam.	Watts	Volts	Max. Amp. at any Voltage	Watts	Volts	Max. Amp. at any Voltage
Candelabra	½ in.	75	125	¾	75	125	1
Medium	1 "	250	250	2½	660	250	6
		(a) 660	250	6	660	600	
Mogul	1½ in.				1,500	250	
		(b)			1,500	600	

(a) This rating may be given only to sockets having a switch mechanism which produces both a quick "make" and a quick "break" action.

(b) Ratings to be assigned later, pending further discussion with manufacturers.

Miniature sockets and receptacles having screw shells smaller than the candelabra size may be used for decorative lighting systems, Christmas tree lighting outfits, and similar purposes.

Double-ended Sockets.—Each lamp holder to be rated as specified above, the device being marked with a single marking applying to each end.

In addition to these there is the Edi-Swan base, which is $\frac{5}{8}$ inch diameter, and has bayonet-type connections and is sometimes used on automobiles and other places where there is much jarring. The Edison miniature base is $\frac{3}{8}$ inch in diameter and is used only for low voltages. Some very small lamps are made without bases, the wires connecting direct to lamp terminals. The mogul socket is used for series incandescent lighting and often fitted with automatic cut-out. It is also used for gas-filled lamps of 300 watts or over. Fiber lined or brass shell sockets should not be used in damp places, or where corrosive vapors exist. Key sockets should also be avoided in damp places, or where inflammable gases may exist.

Sparking Distances.—Very high-test voltages are often measured by their sparking distance. The following table gives the sparking distances between sharp points corresponding to different alternating current voltages, when the ratio between maximum and mean effective voltages is equal to 1.41, or the square root of two. The values given were derived from a long series of careful and accurate tests.

TABLE LXXII

(Copyright, 1906, by Standard Underground Cable Co.)

Volts	Spark Distance A. or B.	Volts	Spark —Distance— A.	B.	Volts	Spark —Distance— A.	B.
1,000	0.028	18,000	0.945	0.945	35,000	1.840	1.895
2,000	0.098	19,000	0.995	0.995	36,000	1.900	1.958
3,000	0.159	20,000	1.042	1.042	37,000	1.945	2.020
4,000	0.216	21,000	1.092	1.097	38,000	2.012	2.085
5,000	0.270	22,000	1.143	1.150	39,000	2.062	2.153
6,000	0.324	23,000	1.195	1.206	40,000	2.127	2.220
7,000	0.378	24,000	1.247	1.260	41,000	2.190	2.290
8,000	0.432	25,000	1.300	1.314	42,000	2.247	2.360
9,000	0.487	26,000	1.353	1.373	43,000	2.308	2.434
10,000	0.540	27,000	1.405	1.427	44,000	2.370	2.506
11,000	0.595	28,000	1.460	1.485	45,000	2.432	2.580
12,000	0.644	29,000	1.512	1.540	46,000	2.495	2.660
13,000	0.695	30,000	1.566	1.600	47,000	2.560	
14,000	0,746	31,000	1.620	1.655	48,000	2.625	
15,000	0.797	32,000	1.675	1.712	49,000	2.692	
16,000	0.845	33,000	1.728	1.772	50,000	2.760	
17,000	0.897	34,000	1.785	1.833			

SPARKING DISTANCES IN INCHES.

Column *A* gives spark distances with 10 inch concave metal shields, the plane of whose edges was 1 inch back of the needle points. Column *B* gives the spark distances without shields.

Sharp needles are essential for uniform spark distances, as points measuring from 0.001 inch to 0.002 inch gave in many instances spark distances that were from 20 to 45 per cent greater than those obtained with sharp points. See also table of A. I. E. E. in Standardization Recommendations.

Specific Gravity (Solids).—The specific gravity of a substance is defined as the ratio of the weight of that substance to the weight of an equal volume of water or air. Water is used as the standard of liquids and solids. Air at the temperature 0°, C. (32° F.) and 766 mm. mercury pressure for gases. By multiplying the specific gravity of any substance by the weight

of an equal volume of water we find the weight of that volume of the material. The weight of a cubic foot of water is approximately 62.5 lbs. The weight of a gallon is approximately 8.33 lbs. To find the specific gravity of a body heavier than water approximately by experiment, weigh it in air and then weigh it in pure water. Divide the weight in air by the loss of weight (buoyancy) in water and the quotient will give the specific gravity. If the body is lighter than water load it down with a substance heavy enough to sink it. Then weigh the two submerged together. Also weigh both separately in air and the heavy body in water. Subtract the buoyancy of the heavy body from the buoyancy of the two bodies together. The remainder will be the buoyancy of the lighter body by which its weight in air is to be divided as before.

Specifications.—In many cases preliminary specifications, setting forth what the purchaser desires, are made out. Unless these are quite broad many dealers or manufacturers may not be able to comply with them and for this reason often submit specifications of their own, and thus the final specifications which form the basis of contracts must be somewhat modified.

In general, specifications may be divided into two parts: one part which deals with machinery and materials, and another which deals with the installation work and results to be obtained. If certain materials are specified, and at the same time requirements as to certain results are made, there is always a chance for disputes as to who is responsible in case the installation does not fulfill requirements. Unless the work is to be carried on under the supervision of a consulting engineer, it is best to give the contractor free choice of materials and hold him entirely responsible for the final result.

All specifications should be based upon the standards of the engineering societies governing the particular kind of work. The A. I. E. E. have standardization rules which govern everything electrical, but these do not largely concern themselves with safety rules. In this regard the National Electrical Code should be adopted as the standard and all material and workmanship should be specified to conform with its requirements. This is a reliable guide in every respect except that of economy and efficiency and suitability of systems, etc. It deals only with safety and reliability.

It is best always to have some sort of a plan showing location of cut-out centers, switches, lights and motors, or any other parts about which there may afterwards be disputes. If there are no plans the location of cut-outs and other conspicuous elements should be mentioned in the specifications. They should also mention how much conduit, open or molding work is to be used. Every item mentioned should form a clause and these should be numbered for reference.

Where accurate calculations are to be made, all circuits and runs of wire should be measured and the specifications thoroughly read and considered. The estimator should take plenty of time to understand every phase of his job. As a reminder of the many items so easily overlooked, he should have prepared an estimate sheet on the order of that following which is furnished by courtesy of the National Electrical Contractors' Association. Large apartments, hotels, etc., usually have many floors and rooms which are exact duplicates, and very careful measurements of one floor or room will answer for the whole building or that part of it which is typical.

Table LXXIII shows approximate quantities of material used for rough wiring in average flats.

TABLE SHOWING APPROXIMATE QUANTITY OF ROUGH MATERIAL PER OUTLET IN AVERAGE FLATS.	Ft. Single Wire.	Ft. Twin Wire.	Ft. Loom.	Ft. Moulding.	No. Insulators.	No. Tubes.	Ft. Conduit.	No. Elbows.	No. Outlet Boxes.	No. Lock Nuts and Bushings.	No. Couplings, Extra.	Lb. Nails.	Oz. Brads.	Rolls Tape, Each Kind.
All Center Lights. No Switches, Conduit	....	16	....	....	....	....	15	1	1	4	1	....	....	....
All Center Lights. No " K and Tube, Loop	32	....	$3\frac{1}{2}$	....	8	16	....	....	....	....	....	$\frac{1}{8}$	....	....
All Center Lights. No " K and Tube, Taps	28	....	2	....	7	14	....	....	....	....	....	$\frac{1}{8}$	....	....
All Center Lights. No " Moulding	28	....	....	13	....	2	....	....	....	....	....	$\frac{1}{8}$	$\frac{1}{2}$	....
All Center Lights. Switches, Conduit	....	15	....	....	....	....	14	1	1	4	1	....	....	....
All Center Lights. Switches, K and Tube, Loop	30	....	$3\frac{1}{2}$	....	7	14	....	....	....	....	....	$\frac{1}{8}$	....	....
All Center Lights. Switches, K and Tube, Taps	24	....	2	....	6	12	....	....	....	....	....	$\frac{1}{8}$	....	....
All Center Lights. Switches, Moulding	24	....	....	12	....	2	....	....	....	....	....	$\frac{1}{8}$	$\frac{1}{2}$	....
All Brackets. No Switches, Conduit	....	22	....	....	....	...	21	1	1	4	1	....	....	....
All Brackets. No " K and Tube, Loop	44	....	$3\frac{1}{2}$	....	11	22	....	....	....	....	....	$\frac{1}{8}$	....	....
All Brackets. No " K and Tube, Taps	35	....	2	....	9	18	....	....	....	....	....	$\frac{1}{8}$	....	....
All Brackets. No " Moulding	35	....	....	17	..	2	....	....	....	....	..	$\frac{1}{8}$	$\frac{1}{2}$	....

In using this table, count all switches except those located in cutout boxes or on fixtures as outlets.

Ceilings are assumed to be 10 feet high; switches 4 feet from floor and brackets 6 feet. All runs have been figured at right angles, so that a small saving can be made with diagonal runs.

National Electrical Contractors' Association Universal Estimate Sheet.

	Bid Goes to.................	
	Address	
No. Lights........	Architect or Engineer.......	
No. Switches......	Address Arch. or Engr.......	
No. Circuits.......		
No. Base Plugs....	Name of Job or Building.....	Estimate No...
No. Telephones....	Location of Job of Building..	Sheet No......
No. Motors........		
H. P. Motors......	See Mr.....Telephone No....	Date..... 19..
No. Fixtures.......	Bid Must Be In by......M..	
K. W. Generator..		
Switchboard	Salesman	Job No........

Material Estimated by   Labor Estimated by   Priced by   Approved by

Conduit, Rigid	Knife Switches	Screws
Conduit Elbows	Door Switches	Nails
Conduit Bushings	Pendant Switches	Toggle Bolts
Conduit Straps	Rubber Covered Wire	Annunciators
Conduit Hangers	Lead Covered Wire	Annunciator Wire
Lock Nuts	Fixture Wire	Annunciator Cable
Conduit Flexible	Special Wire	Elevator Cable
Conduit Fittings	Lamp Cord	Bells
Conduit, Non-Metallic	Reinforced Cord	Buzzers
Ceiling Boxes	Packing House Cord	Push Buttons
Bracket Boxes	Show Window Cord	Silk Cord
Switch Boxes	Molding Wood	Door Openers
Floor Boxes	Molding Metal	Burglar Alarm
Box Covers	Molding Fitting	Batteries
Fixture Hangers	Fixtures	Bell Ringers
Cutout Cabinets	Clusters	Telephones
Panelboards	Key Sockets	Telephone Cable
Metering Panels	Keyless Sockets	Speaking Tube
Meter Loops	Wall Sockets	Whistles
Cutout Boxes	Rosettes	Letter Boxes
Asbestos	Socket Bushings	Tape
Cut Out Blocks	Cord Adjusters	Solder
Fuse Plugs	Shades	Compound
Enclosed Fuses	Shadeholders	Acid
Flush Switches	Adapters	Oil
D. P. Flush Switches	Attachment Plugs	Car Fare
3 Way Flush Switch	Lamps, Incandescent	Cartage
4 Way Flush Switch	Lamp Guards	Bond
Snap Switches	Arc Lamp	Drafting
D. P. Snap Switches	Cleats	Inspection
3 Way Snap Switch	Knobs	Incidentals
4 Way Snap Switch	Tubes	

Bid Sent to Following:	Total	
	Material	
	Labor	
	Overhead Expenses	Per cent
	Profit	Per cent
	Bid	

Figures 23, 24 and 25 will assist in illustrating the most economical manner of running wires for branch circuits. In Figure 23 the heavy black lines denote the mains, and at their terminals the cut-outs are located. It is never economical to push mains any farther than is necessary to enable one branch circuit to reach the far end of the space to be covered. In the arrangement shown in Figure 23 the greatest possible economy would be effected if a cut-out were

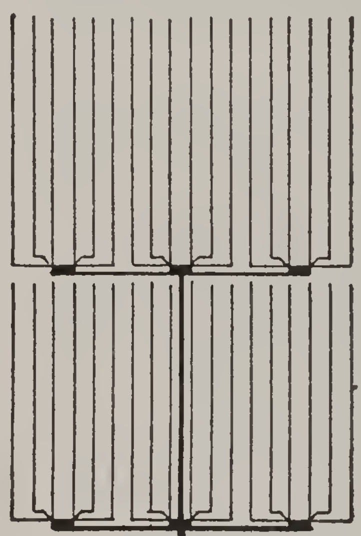


Figure 23.—Comparison of Materials.

provided for each circuit, but for various reasons this is not advisable. The next best arrangement is to provide a number of cut-out centers as shown in the figure, locating each cut-out in the center of the group it is to supply.

In case a given number of lights are to be fed with wires running at right angles, the most economical arrangement can be found by running a straight line through the space covered at such point as to leave an equal number of lights on each side of it, as in Figure 24.

If the lights are to be fed by diagonal runs, the shortest runs can be quickly found by bearing in

mind that from the cut-out center, or from any outlet, this point in connection with any two other outlets forms a triangle and it is merely necessary to avoid using the longest side of this triangle. The position

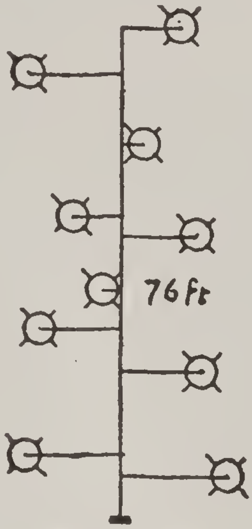


Figure 24.

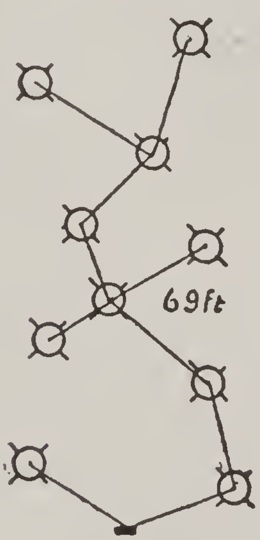


Figure 25.

of lamps shown in Figures 24 and 25 is identical, but Figure 25 requires about 10 per cent less material than Figure 24. The relative economy of running mains or branch circuits can be determined by Table LXXIV, which gives the equivalent in mains of various sizes and branch circuits of 660 watt capacity.

TABLE LXXIV

Showing Mains and Their Equivalent in No. 14 Branch Circuits.

2 Wire Mains	2 Wire Branches	3 Wire Mains	3 Wire Branches
2 ft. No. 14=	4 ft. No. 14	3 ft. No. 14=	10 ft. No. 14
2 ft. No. 12=	6 ft. No. 14	3 ft. No. 12=	12 ft. No. 14
2 ft. No. 10=	8 ft. No. 14	3 ft. No. 10=	16 ft. No. 14
2 ft. No. 8=	10 ft. No. 14	3 ft. No. 8=	22 ft. No. 14
2 ft. No. 6=	16 ft. No. 14	3 ft. No. 6=	32 ft. No. 14
2 ft. No. 5=	18 ft. No. 14	3 ft. No. 5=	36 ft. No. 14
2 ft. No. 4=	22 ft. No. 14	3 ft. No. 4=	44 ft. No. 14
2 ft. No. 3=	26 ft. No. 14	3 ft. No. 3=	52 ft. No. 14
2 ft. No. 2=	30 ft. No. 14	3 ft. No. 2=	60 ft. No. 14
2 ft. No. 1=	32 ft. No. 14	3 ft. No. 1=	64 ft. No. 14
2 ft. No. 0=	40 ft. No. 14	3 ft. No. 0=	80 ft. No. 14
2 ft. No. 00=	50 ft. No. 14	3 ft. No. 00=	100 ft. No. 14
2 ft. No. 000=	58 ft. No. 14	3 ft. No. 000=	116 ft. No. 14
2 ft. No. 0000=	74 ft. No. 14	3 ft. No. 0000=	148 ft. No. 14

Street Lighting.—In villages and suburbs, the street lighting is often of a perfunctory nature. It consists often merely of an incandescent or arc lamp placed at each street intersection. Such lights should be over center of streets. In parks, the object of the illumination must be not merely the road or path, but fields and lagoons as well. At band-stands and similar places, arc lamps are preferable, but where the lights must be brought down under trees they are not very serviceable. Along curved driveways place lights on the outer curve; this will enable drivers to see farther, but will require more material.

In business streets a very brilliant illumination is often desired. Tungsten lamps, installed on posts,

are the most common illuminants at present where a permanent installation is contemplated. For temporary effects festoons are much used. The systems upon which such lights are operated will usually be governed by that which is already in use. The following points should be noted in connection with street lighting: Large units are most economical in first cost, but waste much of their light outside of the street. At street intersections this waste is not so great. Large units should always be hung high. A bright illumination, except on business streets, is not necessary, but the light should be white. For series incandescent lighting special lamps are always used. The thicker the filament the less will the flickering effect of low frequencies affect them. For overhead work wires smaller than No. 6 are seldom used. No incandescent lamp should ever be used outside without a reflector to prevent light being wasted on the upper air. Time switches are often serviceable on street lighting. Those who undertake to install a system of street lighting should prepare themselves for an unlimited amount of annoyance from residents who imagine their trees will be ruined or who quarrel about the location of poles and lamps.

Switches.—The standard height of switches in offices and residences is 4 ft. 6 in. above finished floor. If switches of the push button type are used the white button should be uppermost. Switches should contain sufficient metal to prevent a temperature rise of over 28° C. (50° F.). There should be a contact surface of about 1 sq. in. for every 75 amperes. To obtain this contact surface large capacity switches are made up of a number of blades in parallel. This arrangement also allows better radiation. The following table shows the capacity of single blades of dimensions given, the clip being assumed as of same width.

TABLE LXXV

Width, in.	1/4	3/8	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8
Amperes	8	15	30	58	85	115	150	180	215	280	330	395

These widths will not determine capacity of switch unless the temperature rise is within the limits. Below are given the dimensions and spacings of knife switches as required by the N. E. C. Over all dimensions of standard knife switches as made by the George Cutter Company are given on pages 226 and 230.

Spacings and Dimensions.—Spacings and dimensions must be at least as great as those given in the following tables:

TABLE LXXVI

Not over 125 volts d. c. and a. c.
For switchboards and panel boards:

	Width and Thickness Blades	Width and Thickness Clips and Hinges	Minimum separation of nearest metal parts of opposite polarity	Minimum break distance
30 amp.	1/2 x 5/64 in.	1/2 x 3/64 in.	1 in.	3/4 in.
60 amp.			1 1/4 in.	1 in.

TABLE LXXVII

Not over 125 volts d. c. and a. c.
For individual switches:

	Inch	Inch	Inch	Inch
30 amp.	1/2 x 5/64	1/2 x 3/64	1 1/4	1
60 & 100 amp.			1 1/2	1 1/4
200 amp.			2 1/4	2
400 & 600 amp.			2 3/4	2 1/2
800 & 1000 amp.			3	2 3/4

A 300-ampere switch with the spacings of the 200-ampere switch above may be used on switchboards.

TABLE LXXVIII

250 volts only d. c. and a. c.
For all switches:

	Inch	Inch	Inch	Inch
30 amp.	$\frac{1}{2}$x$\frac{5}{64}$	$\frac{1}{2}$x$\frac{3}{64}$	$1\frac{3}{4}$	$1\frac{1}{2}$

TABLE LXXIX

Not over 250 volts d. c. nor over 500 volts a. c.
For all switches:

	Inch	Inch	Inch	Inch
30 amp.	$\frac{5}{8}$x$\frac{1}{8}$	$\frac{5}{8}$x$\frac{1}{16}$	$2\frac{1}{4}$	2
60 & 100 amp.			$2\frac{1}{4}$	2
200 amp.			$2\frac{1}{2}$	$2\frac{1}{4}$
400 & 600 amp.			$2\frac{3}{4}$	$2\frac{1}{2}$
800 & 1000 amp.			3	$2\frac{3}{4}$

A 300-ampere switch with the spacings of the 200-ampere switch above may be used on switchboards.

Cut-out terminals on switches for over 250 volts must be designed and spaced for 600-volt fuses.

TABLE LXXX

Not over 600 volts d. c. and a. c.
For all switches:

	Inch	Inch	Inch	Inch
30 amp.	$\frac{5}{8}$x$\frac{1}{8}$	$\frac{5}{8}$x$\frac{1}{16}$	4	$3\frac{1}{2}$
60 amp.			4	$3\frac{1}{2}$
100 amp.			$4\frac{1}{2}$	4

Auxiliary contacts of either a readily renewable or a quick-break type or the equivalent are recommended for d. c. switches, designed for over 250 volts, and must be provided on d. c. switches designed for use in breaking currents greater than 100 amperes at a voltage of over 250.

For 3-wire direct current and 3-wire single phase systems the separation and break distances for plain 3-pole knife switches must not be less than those required in the above table for switches designed for the voltage between neutral and outside wires.

TABLE LXXXI

CUTTER KNIFE SWITCHES

See Figure 26

Dimensions, in Inches, for Paragon Switches

Cap. Amps.	A 250V.D.C. 500V. A.C.	A 600V. D.C. or A.C.	B 125V. D.C. or A.C.	B 250V. D.C. or A.C.	B 500V. A.C.	B 600V. D.C. or A.C.	C	D 250 V.D.C. 500V. A.C.	D 600V. D.C. or A.C.	E	F	G Diam. of Stud	H Diam. of Screw	J Diam. of Screw
†30....	5	7	1¾	2¼	..	4½	1⅜	2	4	1⅜	3⅛	¼	11/64	11/64
60....	6½	8½	2⅛	2⅞	3½	5⅛	1 15/16	2⅝	4⅝	1⅝	3¼	5/16	11/64	11/64
100....	7⅜	9¼	2¼	3	3½	5¼	2⅜	3	4⅞	2	4	½	7/32	7/32
200....	10	12¾	3¼	3½	3¾	6	3½	3¾	6¼	2⅞	4	⅝	7/32	7/32
*300....	10¾	13¼	3½	3¾	..	6¼	4⅜	4	6½	3⅜	4	⅝	¼	¼
400....	12	14¼	4½	4½	4½	7	4 15/16	4¾	7	4 3/16	4½	¾	¼	¼
600....	13	15¼	4¾	4¾	5	7¼	6¼	5¼	7½	5⅛	4⅞	1	⅜	⅜
800....	12	16⅜	5	5	5¾	8	6½	4¾	7¾	4 3/16	5⅜	1⅛	⅜	⅜
1000....	13¾	17⅛	5¼	5¼	6¼	8¼	7	5	8¼	5⅛	5½	1¼	⅜	⅜
1500....	14	18	6¼	6¼	..	8½	..	5½	8¼	5⅛	6⅛	1½	½	..
2000....	15	18	7¼	7¼	..	9¼	..	6	8¼	6	6¾	1¾	½	..

TABLE LXXXI—Continued

Cap. Amps.	K		L		M		N	O			P	R	U
	250 V. D.C. 500 V. A.C.	600 V. D.C. or A.C.	250 V. D.C. or A.C.	600 V. D.C. or A.C.	250 V. D.C. or A.C.	600 V. D.C. or A.C.		250 V. D.C. or A.C.	500 V. A.C.	600 V. D.C. or A.C.			
†30.........	$2\frac{7}{8}$	$4\frac{7}{8}$	3	6	$1\frac{1}{2}$	$4\frac{1}{2}$	$\frac{5}{8}$	5	..	10	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{1}{2}$
60.........	$3\frac{11}{16}$	$5\frac{11}{16}$	$4\frac{3}{16}$	$6\frac{11}{16}$	$2\frac{3}{8}$	$4\frac{7}{8}$	$\frac{3}{4}$	$6\frac{13}{16}$	$9\frac{5}{16}$	$11\frac{5}{16}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{8}$
100.........	$4\frac{3}{8}$	$6\frac{1}{4}$	$7\frac{3}{8}$	$9\frac{3}{8}$	$4\frac{7}{8}$	$6\frac{7}{8}$	$1\frac{1}{8}$	$10\frac{3}{8}$	$12\frac{3}{8}$	$14\frac{1}{4}$	1	1	$\frac{3}{4}$
200.........	$5\frac{11}{16}$	$8\frac{3}{16}$	$9\frac{1}{8}$	$11\frac{5}{8}$	$5\frac{3}{4}$	$8\frac{1}{4}$	$1\frac{5}{8}$	$12\frac{7}{8}$	$15\frac{3}{8}$	$17\frac{7}{8}$	$1\frac{7}{16}$	$1\frac{1}{4}$	1
*300.........	$6\frac{1}{4}$	$8\frac{3}{4}$	..	..	..	..	..	..	..	..	$1\frac{5}{8}$	..	$1\frac{1}{4}$
400.........	$7\frac{3}{8}$	$9\frac{5}{8}$	$11\frac{5}{8}$	$14\frac{5}{8}$	$6\frac{3}{4}$	$9\frac{3}{4}$	$2\frac{3}{8}$	$16\frac{3}{8}$	$19\frac{3}{8}$	$21\frac{5}{8}$	$1\frac{7}{8}$	$1\frac{3}{4}$	$1\frac{1}{2}$
600.........	$8\frac{3}{8}$	$10\frac{5}{8}$	14	17	$8\frac{1}{8}$	$11\frac{1}{8}$	3	$19\frac{1}{4}$	$22\frac{1}{4}$	$24\frac{1}{2}$	$2\frac{1}{4}$	2	$1\frac{3}{4}$
800.........	$8\frac{1}{8}$	$11\frac{1}{8}$	$15\frac{3}{16}$	$18\frac{3}{16}$	$8\frac{15}{16}$	$11\frac{5}{16}$	3	$19\frac{15}{16}$	$22\frac{15}{16}$	$25\frac{15}{16}$	$2\frac{3}{8}$	$2\frac{1}{4}$	2
1000.........	$8\frac{3}{4}$	12	17	20	$9\frac{3}{4}$	$12\frac{3}{4}$	$3\frac{5}{8}$	22	25	$28\frac{1}{4}$	$2\frac{5}{8}$	$2\frac{1}{2}$	$2\frac{1}{4}$
1500.........	$9\frac{5}{8}$	..	..	..	..	..	..	..	..	..	$2\frac{7}{8}$	$2\frac{3}{4}$	$2\frac{1}{2}$
2000.........	$10\frac{7}{8}$	..	..	..	..	..	..	..	..	..	$3\frac{1}{8}$	$3\frac{1}{2}$	$3\frac{1}{2}$

†30-ampere switches for use on 500 volts A. C. will take dimensions of 60-ampere switches, except for fuse spacings.

*300-ampere switches, unfused.

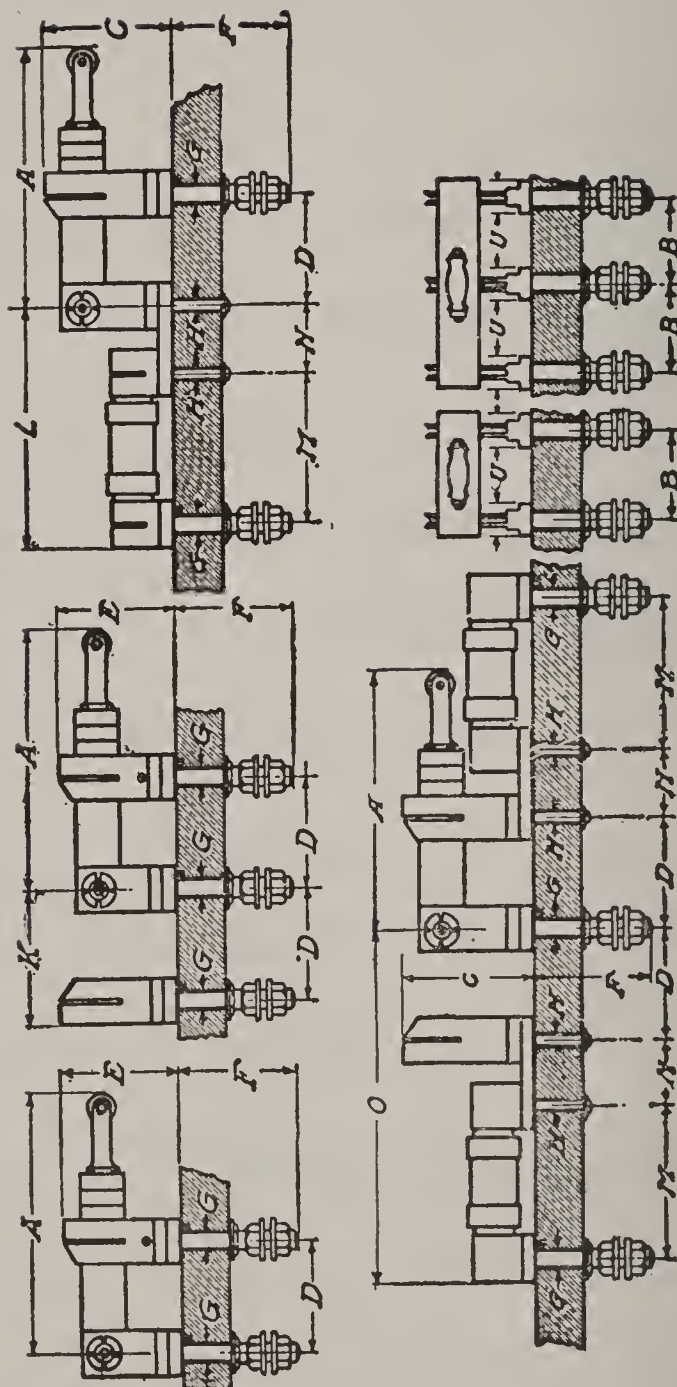


Figure 26.—Cutter Knife Switches Paragon Type.

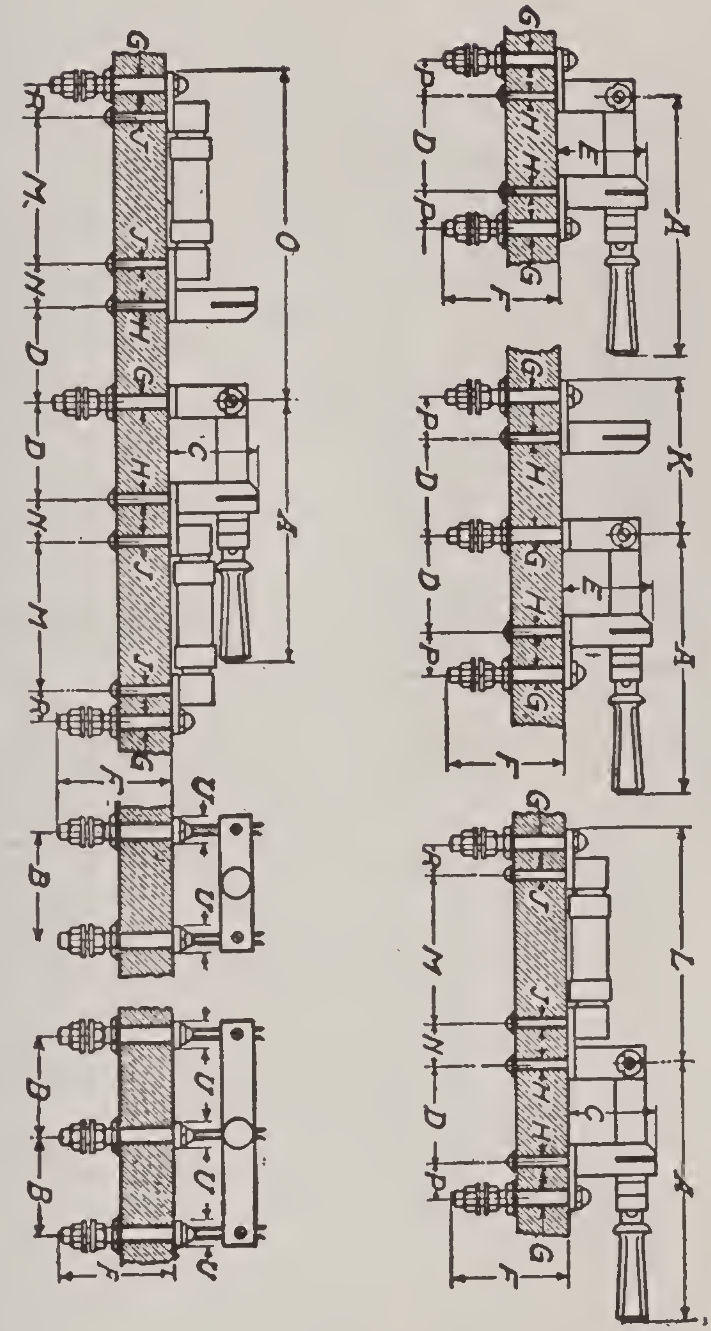


Figure 27.—Cutter Knife Switches Type FF.

TABLE LXXXII

CUTTER KNIFE SWITCHES

See Figure 27

Dimensions, Inches, for Type FF Switches

Cap. Amps.	A: Spade Handle 250 V. D.C. 500 V. A.C.	A: Spade Handle 600 V. D.C. or A.C.	A: Straight Handle 250 V. D.C. 500 V. A.C.	A: Straight Handle 500 V. D.C. or A.C.	A: 125 V. D.C. or A.C.	B: 250 V. D.C. or A.C.	B: 500 V. A.C.	B: 600 V. D.C. or A.C.	C	D: 250 V. D.C. 500 V. A.C.	D: 600 V. D.C. or A.C.	E	F
†30	$4\frac{13}{16}$	$6\frac{13}{16}$	$5\frac{1}{4}$	$7\frac{1}{4}$	$1\frac{3}{4}$	$2\frac{1}{4}$	..	$4\frac{1}{2}$	$1\frac{9}{16}$	$2\frac{1}{8}$	$4\frac{1}{8}$	$1\frac{9}{16}$	$3\frac{1}{8}$
60	$6\frac{1}{2}$	$8\frac{1}{2}$	$6\frac{3}{4}$	$8\frac{3}{4}$	$2\frac{1}{8}$	$2\frac{7}{8}$	$3\frac{1}{2}$	$5\frac{1}{8}$	$2\frac{1}{8}$	$2\frac{7}{8}$	$4\frac{7}{8}$	$2\frac{1}{8}$	$3\frac{1}{4}$
100	$7\frac{7}{8}$	$9\frac{7}{8}$	$7\frac{7}{8}$	$9\frac{7}{8}$	$2\frac{1}{4}$	3	$3\frac{1}{2}$	$5\frac{1}{4}$	$2\frac{3}{4}$	$3\frac{1}{8}$	$5\frac{1}{8}$	$2\frac{3}{4}$	4
200	$9\frac{1}{4}$	$11\frac{5}{8}$	$9\frac{3}{4}$	$12\frac{1}{8}$	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	6	$3\frac{15}{16}$	$3\frac{7}{8}$	$6\frac{1}{4}$	$3\frac{15}{16}$	4
*300	$10\frac{1}{8}$	$13\frac{1}{8}$	$10\frac{5}{8}$	$12\frac{7}{8}$	$3\frac{1}{2}$	$3\frac{3}{4}$	..	$6\frac{1}{4}$	$4\frac{7}{16}$	$4\frac{1}{4}$	$6\frac{1}{2}$	$4\frac{7}{16}$	$4\frac{1}{2}$
400	$11\frac{5}{16}$	$14\frac{13}{16}$	12	$14\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{1}{2}$	7	$5\frac{1}{8}$	$4\frac{3}{4}$	$7\frac{1}{4}$	$5\frac{1}{8}$	$4\frac{3}{4}$
600	$12\frac{9}{16}$	$15\frac{1}{16}$	$13\frac{1}{2}$	16	$4\frac{3}{4}$	$4\frac{3}{4}$	5	$7\frac{1}{4}$	$5\frac{15}{16}$	$5\frac{1}{4}$	$7\frac{3}{4}$	$15\frac{15}{16}$	$4\frac{7}{8}$
800	$12\frac{3}{16}$	$14\frac{15}{16}$	$13\frac{5}{8}$	$16\frac{3}{8}$	5	5	$5\frac{3}{4}$	8	$5\frac{3}{8}$	5	$7\frac{3}{4}$	$5\frac{3}{8}$	$5\frac{3}{8}$
1000	$13\frac{11}{16}$	$16\frac{7}{16}$	$14\frac{1}{2}$	$17\frac{1}{4}$	$5\frac{1}{4}$	$5\frac{1}{4}$	$6\frac{1}{4}$	$8\frac{1}{4}$	6	$5\frac{1}{2}$	$8\frac{1}{4}$	6	$5\frac{1}{2}$
1500	$14\frac{3}{16}$	$16\frac{11}{16}$	$15\frac{1}{2}$	18	$6\frac{1}{4}$	$6\frac{1}{4}$	..	$8\frac{1}{2}$	$6\frac{1}{8}$	$5\frac{3}{4}$	$8\frac{1}{4}$	$6\frac{1}{8}$	$6\frac{1}{8}$
2000	$14\frac{3}{16}$	$16\frac{11}{16}$	$15\frac{1}{2}$	18	$7\frac{1}{4}$	$7\frac{1}{4}$	..	$9\frac{1}{4}$	$6\frac{1}{8}$	$5\frac{3}{4}$	$8\frac{1}{4}$	$6\frac{1}{8}$	$6\frac{3}{4}$
3000	$17\frac{7}{16}$	$19\frac{11}{16}$	$17\frac{5}{8}$	$19\frac{7}{8}$	$7\frac{3}{4}$	$7\frac{3}{4}$	..	$9\frac{3}{4}$	8	7	$9\frac{1}{4}$	8	8
4000	$17\frac{7}{16}$	$19\frac{11}{16}$	$17\frac{5}{8}$	$19\frac{7}{8}$	$8\frac{3}{4}$	$8\frac{3}{4}$	..	$10\frac{3}{4}$	$8\frac{1}{4}$	7	$9\frac{1}{4}$	$8\frac{1}{4}$	9

TABLE LXXXII—Continued

Cap. Amp.	G Diam. of Stud	H Diam. of Screw	K 250V. D. C. 500V. A. C.	K 600V. D. C. or A. C.	L 250V. D. C. or A. C.	L 600V. D. C. or A. C.	M 250V. D. C. or A. C.	M 600V. D. C. or A. C.	N	O 250V. D. C. or A. C.	O 500V. A. C.	O 600V. D. C. or A. C.	U
†30....	$\frac{1}{4}$	$\frac{11}{64}$	$2\frac{3}{8}$	$4\frac{3}{8}$	$2\frac{1}{2}$	$5\frac{1}{2}$	$1\frac{1}{2}$	$4\frac{1}{2}$	$\frac{3}{4}$	$4\frac{5}{8}$	..	$9\frac{5}{8}$	$\frac{1}{2}$
60....	$\frac{5}{16}$	$\frac{11}{64}$	$3\frac{1}{4}$	$5\frac{1}{4}$	$3\frac{11}{16}$	$6\frac{3}{16}$	$2\frac{3}{8}$	$4\frac{7}{8}$	1	$6\frac{9}{16}$	$9\frac{1}{16}$	$11\frac{1}{16}$	$\frac{5}{8}$
100....	$\frac{1}{2}$	$\frac{7}{32}$	$3\frac{5}{8}$	$5\frac{5}{8}$	$6\frac{5}{8}$	$8\frac{5}{8}$	$4\frac{7}{8}$	$6\frac{7}{8}$	$1\frac{5}{16}$	$9\frac{3}{4}$	$11\frac{3}{4}$	$13\frac{3}{4}$	$\frac{3}{4}$
200....	$\frac{5}{8}$	$\frac{7}{32}$	$4\frac{5}{8}$	7	$8\frac{1}{4}$	$10\frac{3}{4}$	$5\frac{3}{4}$	$8\frac{1}{4}$	$1\frac{7}{8}$	$12\frac{1}{8}$	$14\frac{5}{8}$	17	1
*300....	$\frac{3}{4}$	$\frac{1}{4}$	$5\frac{1}{8}$	$7\frac{3}{8}$	..	..	..	..	..	..	..	..	$1\frac{1}{4}$
400....	$\frac{7}{8}$	$\frac{1}{4}$	$5\frac{3}{4}$	$8\frac{1}{4}$	$10\frac{1}{8}$	$13\frac{1}{8}$	$6\frac{3}{4}$	$9\frac{3}{4}$	$2\frac{1}{2}$	$14\frac{7}{8}$	$17\frac{7}{8}$	$20\frac{3}{8}$	$1\frac{1}{2}$
600....	1	$\frac{3}{8}$	$6\frac{1}{2}$	9	$12\frac{3}{16}$	$15\frac{3}{16}$	$8\frac{1}{8}$	$11\frac{1}{8}$	3	$17\frac{7}{16}$	$20\frac{7}{16}$	$22\frac{13}{16}$	$1\frac{3}{4}$
800....	$1\frac{1}{8}$	$\frac{3}{8}$	6	$8\frac{3}{4}$	$13\frac{9}{32}$	$16\frac{9}{32}$	$8\frac{15}{16}$	$11\frac{15}{16}$	$3\frac{1}{8}$	$18\frac{9}{32}$	$21\frac{9}{32}$	$24\frac{1}{32}$	2
1000....	$1\frac{1}{4}$	$\frac{3}{8}$	$6\frac{3}{4}$	$9\frac{1}{2}$	$14\frac{3}{4}$	$17\frac{3}{4}$	$9\frac{3}{4}$	$12\frac{3}{4}$	$3\frac{5}{8}$	$20\frac{1}{4}$	$23\frac{1}{4}$	26	$2\frac{1}{4}$
1500....	$1\frac{1}{2}$	..	7	$9\frac{1}{2}$	..	..	..	..	..	..	..	..	$2\frac{1}{2}$
2000....	$1\frac{3}{4}$	..	7	$9\frac{1}{2}$	..	..	..	..	..	..	..	..	$3\frac{1}{4}$
3000....	2	..	$8\frac{3}{4}$	11	..	..	..	..	..	..	..	..	$3\frac{1}{2}$
4000....	$2\frac{1}{2}$	..	$8\frac{3}{4}$	11	..	..	..	..	..	..	..	..	$4\frac{1}{2}$

†30-ampere switches for use on 500 volts A. C. will take dimensions of 60-ampere switches, except for fuse spacings.

*300-ampere switches, unfused.

Switchboards.—The best material for mounting switches and bus-bars is marble. Slate may be used, but metal veins may cause trouble. A liberal allowance of space should be allowed back of board, and its panels should be kept well above the floor. Where more than one machine is connected it is customary to operate them in parallel on d. c. For dimensions of bus-bars, switches and fuses, see those headings. It is customary to provide the following instruments, etc., for good switchboards: One main three pole switch for each generator, where there are several operated in parallel. One ammeter for each generator, or an ammeter arranged for connection to each machine. A voltmeter which may be connected to any machine, and also be used as a ground detector. One field rheostat for each machine. Sufficient pilot lights to illuminate board properly. In some cases also a wattmeter measuring the total current.

Alternating current boards are also often equipped for parallel running, but not always. In some cases the board is divided and fitted with throw over switches so that either generator may supply everything connected, or only a part of it, as desired.

The following equipment is commonly used: Main switch for each generator. Synchronizing lamps, or synchroscope. Frequency indicator. Power factor indicator. Voltmeter to be used as with d. c. machines. An ammeter for each phase, and also for each generator. Exciter equipment. Wattmeters. To these must of course be added the necessary fuses and switches. The N. E. C., however, does not require fuses on a. c. generator or their exciters. If practicable, light and power circuits should be kept separate.

Symbols.—The following are the symbols recommended by the American Institute of Electrical Engineers.

The following notation is recommended:

Name of quantity	Symbol	Unit
Voltage, e.m.f., potential difference	E, e,	volt
Current	I, i,	ampere
Resistance	R, r,	ohm
Reactance	X, x,	ohm
Impedance	Z, z,	ohm
Admittance	Y, y,	mho
Conductance	G, g,	mho
Susceptance	B, b,	mho
Power	P, p,	watt
Capacity	C, c,	farad
Inductance	L,	henry
Magnetic flux	Φ	maxwell
Magnetic density	B	gauss
Magnetic force	H	gilbert per cm.
Length	L, l,	cm. or inch
Mass	M, m,	gm. or lb.
Time	T, t,	second or hour

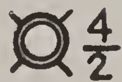
Em, Im and Bm should be used for maximum cyclic values, e, i and p for instantaneous values, E and I for r.m.s. values, and P for the average value or effective power. These distinctions are not necessary in dealing with continuous current circuits. Vector quantities are preferably represented by bold face capitals.

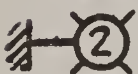
Testing.—It is assumed that the reader of this work is familiar with the general principles employed in testing, and therefore no attempt will be made to explain methods of using the various instruments. The list given in the following pages is intended as a reminder of the various instruments available for different purposes. Those about to undertake testing work with which they are not entirely familiar are advised to consult this list, and select those instruments needed. Consult Standardization Rules of A. I. E. E. and N. E. C. and make tests in conformity with their standards.

STANDARD SYMBOLS FOR WIRING PLANS

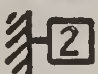
As adopted and recommended by the NATIONAL ELECTRICAL CONTRACTORS ASSOCIATION OF THE UNITED STATES.


Ceiling Outlet; electric only. Numeral in center indicates number of standard 16 c. p. incandescent lamps.


Ceiling Outlet; combination. 4-2 indicates 4-16 c. p. standard incandescent lamps and 2 gas burners.

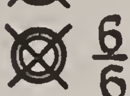

Bracket Outlet; electric only. Numeral in center indicates number of standard 16 c. p. incandescent lamps.


Bracket Outlet; combination. 4-2 indicates 4-16 c. p. standard incandescent lamps and 2 gas burners.


Wall or Baseboard Receptacle Outlet. Numeral in center indicates number of standard 16 c. p. incandescent lamps.


Floor Outlet. Numeral in center indicates number of standard 16 c. p. incandescent lamps.


Outlet for Outdoor Standard or Pedestal; electric only. Numeral indicates number of stand. 16 c. p. incan. lamps.


Outlet for Outdoor Standard or Pedestal; combination. 6-6 indicates 6-16 c. p. stand. incan. lamps; 6 gas burners.


Drop Cord Outlet.


One Light Outlet, for lamp receptacle.


Arc Lamp Outlet.


Special Outlet, for lighting heating and power current, as described in specifications.


Ceiling Fan Outlet.

S^1 S. P. Switch Outlet.

S^2 D. P. Switch Outlet.

S^3 3-Way Switch Outlet.

S^4 4-Way Switch Outlet.

Show as many symbols as there are switches. Or in case of a very large group of switches, indicate number of switches by a Roman numeral, thus: S^1 XII; meaning 12 single pole switches.

Describe type of switch in specifications, that is,

Flush or surface push button or snap.

STANDARD SYMBOLS FOR WIRING PLANS

As adopted and recommended by the NATIONAL ELECTRICAL CONTRACTORS ASSOCIATION OF THE UNITED STATES.

S^D Automatic Door Switch Outlet.

S^E Electrolier Switch Outlet.

 Meter Outlet.

 Distribution Panel.

 Junction or Pull Box.

 Motor Outlet; numeral in center indicates horse power.

 Motor Control Outlet.

 Transformer.

 Main or feeder run concealed under floor.

 Main or feeder run concealed under floor above.

 Main or feeder run exposed.

 Branch circuit run concealed under floor.

 Branch circuit run concealed under floor above.

 Branch circuit run exposed.

 Pole line.

 Riser.

SUGGESTIONS IN CONNECTION WITH STANDARD SYMBOLS FOR WIRING PLANS.

Indicate on plan, or describe in specifications, the height of all outlets located on side walls.

It is important that ample space be allowed for the installation of mains. feeders, branches and distribution panels.

It is desirable that a key to the symbols used accompany all plans.

If mains, feeders, branches and distribution panels are shown on the plans, it is desirable that they be designated by letters or numbers.

STANDARD SYMBOLS FOR WIRING PLANS

As adopted and recommended by the NATIONAL ELECTRICAL CONTRACTORS ASSOCIATION OF THE UNITED STATES.

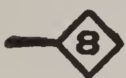
 Telephone Outlet; private service.

 Telephone Outlet; public service.

 Bell Outlet

 Buzzer Outlet.

 2 Push Button Outlet; numeral indicates number of pushes.

 Annunciator; numeral indicates number of points.

 Speaking Tube.

 Watchman Clock Outlet.

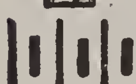
 Watchman Station Outlet.

 Master Time Clock Outlet.

 Secondary Time Clock Outlet

 Door Opener.

 Special Outlet; for signal systems, as described in specifications

 Battery Outlet.

 Circuit for clock, telephone, bell or other service, run under floor, concealed. Kind of service wanted ascertained by symbol to which line connects.

 Circuit for clock, telephone, bell or other service, run under floor above concealed. Kind of service wanted ascertained by symbol to which line connects.

NOTE—If other than standard 16 c. p. incandescent lamps are desired, specifications should describe capacity of lamp to be used.

TABLE LXXXIII

Terminals.—George Cutter Co.

Square Type, Cast.

(See Figure 28.)

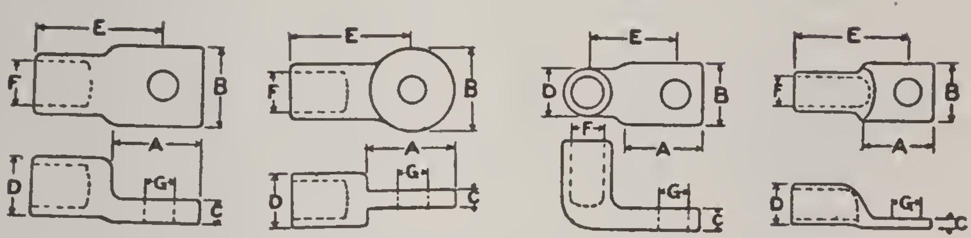


Figure 28.—Terminals.

		Standard Dimensions, Inches						
Amps.	Wire Size	A	B	C	D	E	F	G
30	8	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{5}{16}$	$\frac{3}{4}$	$\frac{3}{16}$	$\frac{3}{16}$
50	5	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{1}{8}$	$\frac{3}{8}$	1	$\frac{7}{32}$	$\frac{3}{16}$
75	3	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{3}{16}$	$\frac{1}{2}$	$1\frac{1}{8}$	$\frac{9}{32}$	$\frac{9}{32}$
100	1	$\frac{13}{16}$	$\frac{3}{4}$	$\frac{3}{16}$	$\frac{17}{32}$	$1\frac{1}{4}$	$\frac{11}{32}$	$\frac{9}{32}$
150	00	$\frac{15}{16}$	$\frac{7}{8}$	$\frac{3}{16}$	$\frac{5}{8}$	$1\frac{3}{8}$	$\frac{7}{16}$	$\frac{13}{32}$
175	000	1	$\frac{15}{16}$	$\frac{1}{4}$	$\frac{11}{16}$	$1\frac{1}{2}$	$\frac{1}{2}$	$\frac{13}{32}$
200	0000	$1\frac{1}{16}$	1	$\frac{1}{4}$	$\frac{13}{16}$	$1\frac{5}{8}$	$\frac{19}{32}$	$\frac{13}{32}$
250	300000	$1\frac{3}{32}$	1	$\frac{5}{16}$	$\frac{15}{16}$	$1\frac{3}{4}$	$\frac{11}{16}$	$\frac{13}{32}$
300	350000	$1\frac{3}{8}$	$1\frac{1}{4}$	$\frac{3}{8}$	1	2	$\frac{3}{4}$	$\frac{13}{32}$
350	400000	$1\frac{1}{2}$	$1\frac{1}{2}$	$\frac{7}{16}$	$1\frac{1}{16}$	$2\frac{1}{4}$	$\frac{3}{16}$	$\frac{13}{32}$
400	500000	$1\frac{5}{8}$	$1\frac{1}{2}$	$\frac{1}{2}$	$1\frac{1}{4}$	$2\frac{3}{8}$	$\frac{15}{16}$	$\frac{13}{32}$
500	750000	$1\frac{3}{4}$	$1\frac{3}{4}$	$\frac{9}{16}$	$1\frac{3}{8}$	$2\frac{3}{4}$	$1\frac{1}{16}$	$\frac{17}{32}$
600	1000000	2	$1\frac{3}{4}$	$\frac{9}{16}$	$1\frac{9}{16}$	3	$1\frac{3}{16}$	$\frac{17}{32}$
700	1250000	$2\frac{1}{4}$	2	$\frac{5}{8}$	$1\frac{3}{4}$	$3\frac{1}{8}$	$1\frac{5}{16}$	$\frac{17}{32}$
800	1500000	$2\frac{1}{2}$	2	$\frac{5}{8}$	2	$3\frac{1}{4}$	$1\frac{1}{2}$	$\frac{17}{32}$
1000	2000000	$2\frac{5}{8}$	$2\frac{1}{4}$	$\frac{3}{4}$	$2\frac{1}{4}$	$3\frac{3}{8}$	$1\frac{3}{4}$	$\frac{21}{32}$

Round Type, Cast.

Amps.	Wire Size	A	B	C	D	E	F	G
30	8	9/16	9/16	1/8	5/16	3/4	3/16	3/16
50	5	13/16	3/4	3/16	3/8	1 1/8	7/32	3/16
75	3	15/16	7/8	3/16	1/2	1 1/4	9/32	9/32
100	1	1 1/16	1	7/32	1/2	1 3/8	11/32	9/32
150	00	1 1/16	1	1/4	5/8	1 1/2	7/16	13/32
175	000	1 3/16	1 1/8	1/4	11/16	1 1/2	1/2	13/32
200	0000	1 1/4	1 1/4	1/4	13/16	1 3/4	19/32	13/32
250	300000	1 5/16	1 1/4	5/16	15/16	1 7/8	11/16	13/32
300	350000	1 1/2	1 3/8	5/16	1	2	3/4	13/32
350	400000	1 5/8	1 1/2	5/16	1 1/8	2 1/8	13/16	13/32
400	500000	1 3/4	1 5/8	7/16	1 1/4	2 3/8	15/16	13/32
500	750000	2 1/8	1 15/16	1/2	1 3/8	3	1 1/16	17/32
600	1000000	2 3/8	2 1/4	5/8	1 5/8	3 3/8	1 3/16	17/32
700	1250000	2 5/8	2 1/2	3/4	1 3/4	3 7/8	1 5/16	17/32
800	1500000	2 5/8	2 1/4	3/4	2	3 7/8	1 1/2	17/32
1000	2000000	2 3/4	2 1/2	3/4	2 1/4	4	1 3/4	21/32

Right Angle Type, Cast.

Amps.	Wire Size	A	B	C	D	E	F	G
30	8	1/2	3/8	1/8	5/16	9/16	3/16	3/16
50	5	5/8	5/8	1/8	3/8	3/4	7/32	3/16
100	1	13/16	3/4	3/16	1/2	1	11/32	9/32
150	00	1	7/8	5/16	5/8	1 1/8	7/16	11/32
200	0000	1 1/8	1	3/8	13/16	1 3/8	19/32	13/32
300	350000	1 1/4	1 1/4	3/8	1	1 1/2	3/4	13/32
400	500000	1 1/2	1 1/2	3/8	1 1/4	1 3/4	15/16	13/32
600	1000000	2	1 3/4	7/16	1 5/8	2	1 3/16	17/32

Wrought Type.

Amps.	Wire Size	A	B	C	D	E	F	G
25- 50	6	9/16	7/16	3/32	5/16	7/8	3/16	3/16
75-100	3	3/4	9/16	1/8	3/8	1 1/4	1/4	1/4
150	0	15/16	11/16	1/8	1/2	1 1/2	3/8	11/32
200	000	1 1/16	7/8	1/8	5/8	1 3/4	1/2	3/8
300	300000	1 1/4	1 1/8	1/8	3/4	2	5/8	13/32

Ammeter.—In choosing an ammeter one must consider whether it is for a. c., d. c. milli-amperes, full current, or shunt. Special instruments are made for each of these conditions; they are also made recording.

Bond Tester.—This is an instrument made especially for testing the conductivity of rail bonds and rails.

Cable Testing Set.—Usually an instrument capable of locating faults in cables without cutting into the cable.

Capacity Testing Sets.—A portable insulating and capacity testing set is made by the Leeds and Northrup Co. Other cable testing sets can also be used for this purpose.

Current Transformers.—These instruments are used with a. c. circuits where large currents are to be measured; also with wattmeters.

Dynamometer.—This is a special form of galvanometer which may be used for very accurate measurements of either voltage, current or watts. It can also be used for testing capacity and inductance and other tests for which volt or ammeters may be used. It is used mostly for a. c. work.

Electrolytic Conductivity Apparatus.—The internal resistance of batteries can be measured by means of the Wheatstone Bridge, but slight errors are possible. To avoid these errors special apparatus has been constructed.

Electrometer.—This is an instrument the operation of which is based on electric charges; used in laboratories for measuring difference of potentials.

Frequency Meter.—Such instruments are used to determine the frequency of a. c. circuits. They may also be used as speed indicators.

Fault Finder.—This is a name given to certain special forms of testing instruments containing a battery and resistances and arranged to facilitate testing.

Galvanometer.—The galvanometer is a very delicate testing instrument and exists in a variety of forms. It is more delicate than the telephone receiver for d. c., and where there is much noise, but for fluctuating currents the latter is more serviceable.

Gauges.—Wire gauges are used for measuring the diameters of wires, sheet metal, etc. See description under this heading.

Ground Detectors.—Voltmeters and lamps are used for this purpose, as well as special electrostatic instruments.

Hydrometer.—This instrument is frequently required in testing battery solutions.

Illuminometer.—Illuminometers are of various kinds. Some of them are very simple and somewhat crude; others are good photometers, a little more simple and portable than the latter; usually calibrated in foot candles.

Induction Standards.—Self and mutual induction standards are used in connection with the Wheatstone Bridge for comparing inductances.

Iron Loss Watt and Voltmeters.—This is a special instrument made by the Westinghouse Co. for measuring the iron losses in transformers.

Keys.—For high potential or precision work specially constructed keys or switches are employed.

Lamp and Scale.—For reflecting galvanometers a special lamp and scale are often required.

Megger.—This is a trade name for a special testing set gotten out for general purposes.

Meter Testing Sets.—These are special plugs and connections to facilitate the testing of wattmeters.

Micrometer.—This instrument answers the same purpose as the wire gauge, but is much more accurate and can be used for very accurate measurements.

Multipliers.—These are resistances intended to be placed in series with voltmeters and which enable the voltmeters to be used for the measurement of higher voltages.

Ohm-meters.—This is a simplified form of Wheatstone Bridge and is used for the same purposes; measuring resistances, detecting faults, etc.

Oscillograph.—This is an instrument used for recording accurately the variation in the wave form of an alternating current or e. m. f.

Permeability Meter.—The permeability meter is used for testing samples of iron as to their magnetic reluctance, or permeability.

Phase Rotation Indicator.—This is an instrument used in determining direction of rotating field, or in connecting motors, etc.

Photometer.—This device is used to measure intensity or degrees of illumination. Some photometers are cumbersome laboratory instruments; others are portable.

Polarity Indicator.—This is an instrument used to determine the polarity of electric currents; also made to determine the polarity of magnets.

Potential Transformer.—This is a piece of apparatus used mostly for reducing the voltage by a fixed ratio so as to bring it within the range of instruments.

Power Factor Meter.—This piece of apparatus indicates the phase relation between the current and e. m. f. of the circuit, or generator, to which it is connected.

Pyrometer.—The pyrometer is used for measuring heat. Some pyrometers depend upon electrical prin-

ciples for their action. They are sometimes used to determine the temperature of field coils.

Resistances.—Separately mounted resistances are sometimes used in connection with the Wheatstone Bridge and other instruments to enlarge their scope.

Rotating Standard.—This is a wattmeter in which a pointer moves rapidly, its movement being in proportion to the power consumed in the circuit at the time. It is especially designed to facilitate comparison of meters with it.

Sechometer.—This is an instrument used to measure coefficients of self-induction.

Shunts.—These are used in connection with ammeters and so chosen that only a predetermined portion of the total current shall pass through the meter.

Slide Wire Bridge.—This is a modification of the Wheatstone Bridge.

Standardizing Set.—This is usually an arrangement of instruments of high grade which may be used to calibrate or standardize other instruments.

Synchroscope.—This device indicates the phase difference between two currents or e. m. f.'s to which it is connected.

Tachometer.—This is a speed indicator, usually arranged to be held against end of shaft. When fitted also with a stop watch, it is known as a tachoscope.

Telefault.—This is a special type of testing instrument manufactured by Matthews & Bro., which enables certain tests to be made without cutting into the wires; can also be used for locating underground pipes.

Telephone Receiver.—The receiver is very sensitive to fluctuations in current strength and is much used for testing. With d. c. it gives only one click when current is switched on or off. Where there is much noise it is somewhat handicapped.

Thermometers.—These are used in testing machinery and wires. Specially constructed instruments are mostly used.

Voltameter.—An instrument measuring current strength by the amount of electrolyte decomposed.

Volt-ammeter.—An instrument capable of measuring both current and voltage.

Voltmeters.—They are used for measuring p. d. Not all are suitable for a. c. and d. c.; some are electrostatic, some read in milli-volts and are recording.

Wattmeters.—These are used for measuring power. Not all of them are suitable for d. c. and a. c.

Wheatstone Bridge.—This is the best known of all electrical testing instruments. With it more tests can be made than with any other device. It is, however, cumbersome and more difficult to handle than many of the other instruments.

Thawing Water Pipes.—Special stepdown transformers are generally used for a. c. and must have at least 200 amperes capacity for the smaller pipes and should have much more for larger ones. Storage batteries have also been used.

Theatres.—A full treatise on this subject is given in "Motion Picture Operation, Stage Electrics and Illusions."

Arc Pockets.—These should be wired with no smaller than No. 6; switched at the board, and open at the bottom to prevent accumulation of dirt. Large theatres can well use pocket capacity for twenty arc lamps. The pockets should be arranged off stage, as close to the scenery as practicable. Each pocket usually contains four circuits.

Auditorium.—Some auditoriums are thickly studded with lamps, the purpose being to produce decorative effects. In such cases frosted lamps are advisable. The actual illumination may be brought

about by arc lamps, or large chandeliers. Unless decorative effects are striven for, one 50-watt lamp will furnish enough illumination for twenty seats. From two to ten fan motors should be provided for, according to size of theatre. It is impossible to arrange a system of direct lighting in connection with which some of the lights will not be in the range of vision of part of the audience at least. If the expense is not prohibitive cove, or indirect lighting, would be very serviceable. Cove lighting is very useful to show off decorations about proscenium arch.

Balcony.—In the balcony or gallery, provision for several arc lamps should be made. These should also be controllable from the main board. The ceilings in balconies are usually low, and lights must be kept well back to avoid range of vision of spectators. Use inverted lighting or small c.p. lamps kept well up at ceiling. Provide for fan motors.

Blinding Lights.—This is a row of lights sometimes placed about proscenium arch, the purpose being to blind the audience for a few moments to permit a quick change of scenery. Lamps of high intrinsic brilliancy should be used. If decorations are of a light color, or emergency lights must be kept burning, the plan is not very successful. Never frost lamps used for this purpose.

Borders.—From one to six borders, according to size and pretensions of house, are installed. Feed borders to center. Leave cables long enough so borders may be lowered to within five feet of stage floor. Use slow-burning wire and arrange for color circuits. Borders should be suspended by wire rope and insulated. Lamps are placed from six to twelve inch centers. The proportion of white and colored lamps is: two white, one red and one blue. Some borders are provided with a special circuit providing just light enough for rehearsals.

Bridges.—This is a name given to small galleries usually located at each side of proscenium and opening on stage side. Arc lamps are often operated from these bridges and arc pockets should be provided. This is also a good place from which to connect stage chandeliers.

Bunch Lights.—These lights are mostly fed out of stage pockets. The bunch circuits should be switched at the board, and some of them at least should be grouped with color circuits. Plugs used for incandescent circuits on stage should not be interchangeable with arc lamp plugs.

Canopies.—Most theatres are equipped with canopies in front of house. These are often studded with lights. Arrange for low-wattage lamps and have them frosted. Arrange lamps to be out of weather. Sometimes provision is made for lamps in glass signs; 1320 watts will be allowed per circuit with these lights if they are properly wired for.

Chandeliers.—Large chandeliers are often used in theatres. These should be hung so they may either be raised or lowered for renewal of lamps.

Curtain.—In large cities all theatres are fitted with heavy asbestos and steel curtains. These usually require motors to operate them. In some cities hydraulic operation is required. In some cases the drop curtain is also operated by motor.

Damper.—All good theatres are provided with stage dampers which can be instantly opened in case of a fire on the stage. It is customary to hold the damper closed by an electromagnet, and to place a switch on each side of stage, said switch when opened releasing the magnet and allowing the damper to open.

Dressing Rooms.—Arrange dressing room illumination without cords if possible. Provide circuit for flatiron. Cover each lamp with a strong locked

guard. Arrange lights so that each side of face is illuminated by at least one lamp. Door switches are useful in dressing rooms.

Emergency Lighting.—Every theatre should have an emergency lighting system capable of furnishing sufficient light for the audience to leave the house in case the main system fails. The emergency system should be entirely independent of the other lighting and in no way connected with it. It is customary to provide capacity for about one 25-watt lamp for each 400 square feet of auditorium space. To this emergency system may also be connected a sufficient number of exit lights to indicate doors and fire escapes. Allow no key sockets, fan motors, or other devices on emergency lighting circuits.

Fire Alarm.—Provisions for fire alarm should be made. It is customary to connect the stage with the box office through a signal circuit that can be used for various purposes.

Fire Pump.—This is provided to insure good pressure in case of fire. It must be wired for in the most substantial and reliable manner.

Fly Floor.—This is that part of the gallery above stage, from which stage hands operate the curtains. A few lights only are needed, but they should be located convenient for men lounging between acts.

Footlights.—These form the most important and effective part of the permanently located stage lights. They must be very carefully located so as to illuminate the lower part of stage without obstructing the view of the audience. Lights are generally studded as thickly as possible, and about half of them arranged for white and the other half divided into two colors.

Galleries.—On these pockets for arc lamps, etc., are usually provided.

Grid.—This is the name given to that part of the rigging loft to which sheaves, etc., operating curtains

and drops, are attached. Provide one light for each 400 square feet.

Lobby.—The lobby is usually very brilliantly illuminated, but the lights must be controlled by switches so that most of them may be turned out when the audience is inside. Provide side outlets for picture illumination, etc.; also for portable signs.

Orchestra Lights.—The largest theatres have about 100 outlets for orchestra lights. Less than twenty should not be considered in any first-class house. Place fuses on switchboard and arrange control so that one of the musicians can control lights in dark scenes.

Program Board.—This is an arrangement of lights by which the next number on the program can be given the audience. A special outlet at each side of stage should be provided for it. Run large conduit, as many wires must be accommodated.

Proscenium Side Lights.—These lights are arranged at each side of proscenium opening on stage side. Sometimes they are wired for three colors.

Retiring Rooms.—These are usually wired in imitation of homes, cozy corner effects, table lamps, etc. Illuminate pictures on walls.

Stage Switchboard.—The stage switchboard is usually located on right hand side of stage, facing the audience, and it is preferable to elevate it above stage level. The wiring of a good board should be divided into four parts, each independent of the others. All of the house lights should be controlled by one main switch; the footlights and all of the upper part of stage lighting by another, and the stage pockets by a third. In addition to this there should be a division to which lights that remain in use all of the time are connected. The stage lighting is again divided into three color groups, the white

lights being equal numerically to all of the colored lights.

A list of the circuits which should be independent of all others and make up group four is given in the following:

Dusting circuit.	Fan motor circuit.
Ventilating motor circuit.	Curtain motor.
Orchestra lights.	Dressing room circuits.
Program lights.	Electric signs
Fly floor lights.	Rigging loft lights.
Pilot lights.	

Fig. 29 shows a well-laid-out switchboard. All of the lights in the auditorium are controlled by switches shown in the upper right hand corner, and all of these are under control of the main switch. House lights are usually operated as a unit.

The stage pockets are controlled by the bank of switches shown at F. Lights burning off of stage pockets are generally controlled by special operators or by actors, so that switches need not be so very convenient to switchboard operator. He must, however, have them under his control. In the arrangement shown in Figure 29 the white lights predominate in the ratio of two to one, and are laid out in two groups, *A* and *B*. Both groups are controlled by the switch *C*. The switches *A* and *B* do not control the lights at all if the smaller throw-over switches at the right are thrown downward. A diagram of these switches is given in Figure 30, where the switches *B* and *C* are indicated. The object of the switches *A* and *B* is to help in quickly increasing or decreasing the illumination on the stage. If in the beginning of a certain scene, for instance, only a small quantity of light is wanted, the low illumination may be obtained by throwing the proper switches down; the additional

illumination which will be wanted a few minutes later may be prepared for by setting the other switches needed to the upward position and at the proper

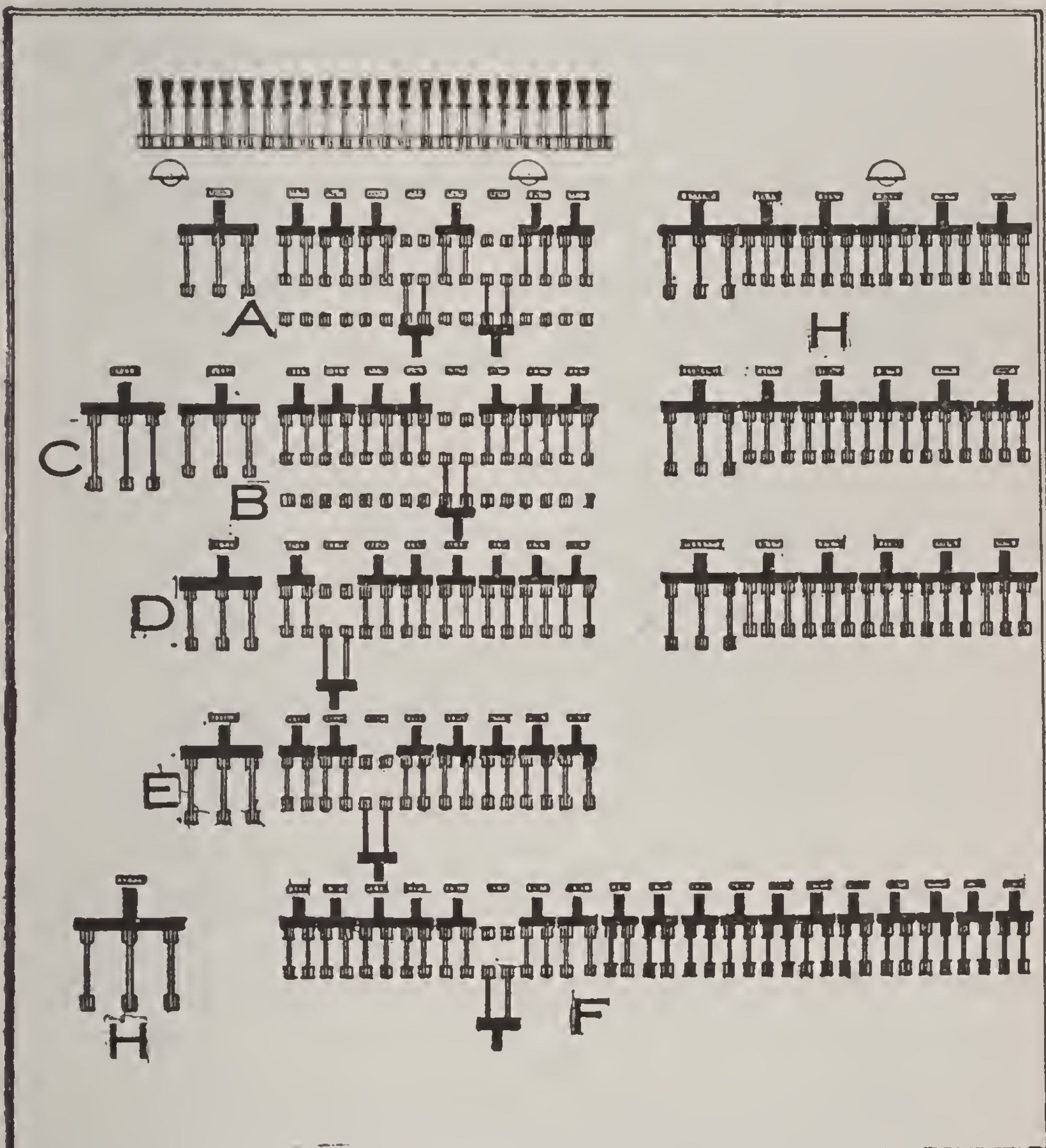


Figure 29.—Stage Switchboard.

moment closing switch *B*. In the same way, by a reversal of the process, the illumination may be instantly reduced. This feature is very valuable in many stage settings. To throw off all of the white

lights the switch *C* must be opened. The switches *D* and *E* are main switches controlling the colored lamps. All lamps of one color should be connected to one or the other of these switches.

From these three groups of switches circuits extend into all borders, proscenium side lights and footlights, so that the color scheme may be carried out in any or all of them.

The handles of all switches in the same row should be of the same height. Switches should be extra heavy. Dimmer handles should be located directly above switches controlling them.

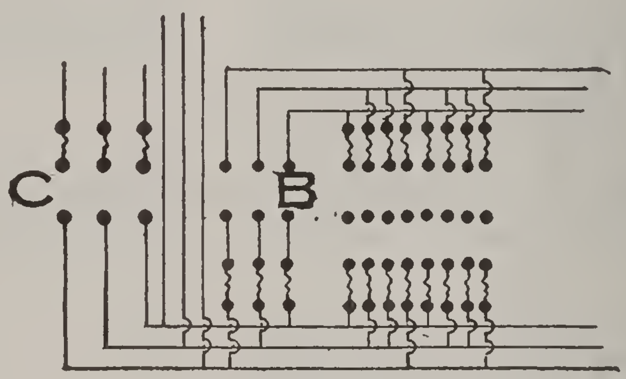


Figure 30.

The fuses or switches controlling lights not usually manipulated by switchboard operator are generally worked into the vacant spaces between the groups mentioned above.

All branch circuits are preferably located behind the board. This will allow of trouble being instantly rectified.

Transformers.—The transformer capacity which must be provided ranges from .20 to .80 percent of the connected load.

The full load efficiency of transformers varies from about 0.95 to 0.985. The smaller transformers are

less efficient than the larger, cost more per K. W., and give poorer regulation. Their installation is, however, much more economical in regard to wire.

Transformers are properly rated in kilo-volt-amperes (K.V.A.). They cannot accurately be rated in K. W. (although this term is often used), because the wattage depends upon the power factor, which is governed mainly by the load and line to which the transformer is connected. The efficiency of a transformer can be found by dividing the output by the input.

The polarity is generally such that the current is entering the primary side at the same time it is leaving the secondary side corresponding to it. Oil cooled transformers are the most reliable, but should not be used where overflowing oil could do harm.

The principal losses are the core or iron losses and the copper losses. The iron losses are the most important in transformers which are idle but connected the greater part of the time. Iron losses are continuous while the transformer is connected, whether it is delivering power or not. The copper losses take place only at time current is being used. The drop in voltage caused by them is proportional to the current, while the power loss is proportional to the square of the current. The iron losses are not of much importance at time of full load, but at this time the copper losses are the most disturbing.

The core losses can be ascertained by measuring the current delivered to the primary side while the secondaries are open and noting the percentage of this to the full load current.

The copper loss can be found by applying voltage enough to the primary wires to cause the full load current to flow in the secondary, which must be short-circuited. This power must be measured by a watt meter and the percentage to the total power noted.

Test all transformers for insulation before connecting.

All transformers should have their secondaries grounded, preferably at some neutral point. Shells of transformers should also be grounded.

Tables for Determining the Most Economical Number and Location of Transformers.—In a territory which has but few customers, and these somewhat scattered, each transformer constitutes a system by itself and is not connected to any other transformer. As the number of customers increases it becomes necessary either to extend the lines from one transformer or provide additional transformers and transfer part of the load to them. If the number of customers keeps on increasing, the mains from the various transformers soon meet, and may then be connected together, although, if transformers are far apart, there is no great advantage in this. Under these circumstances we have a number of transformers feeding a common line extending along a street. Finally, if the customers still increase, or the load becomes greater, lines must be run on cross streets and these are connected to the others and we have a network of wires. In all three stages of the evolution of a secondary system of distribution, the determination of the most economical arrangement of conductors and transformers is an important one. To keep the cost of wiring down to a minimum we must install a large number of small transformers. Small transformers are, however, more expensive in proportion to their capacity than large ones; and full load, as well as all-day efficiency, is also much lower.

The most economical arrangement from the point of view of first cost of installment is that with which the investment for wires plus the investment for transformers is a minimum. There are three different conditions under which it may be necessary to

determine the most advantageous location of transformers: The first is that where a secondary system exists at the terminus of a primary extension. Since the secondary wires usually carry about ten times as much current as the primary, it is generally economical to extend the primary line to the center of the secondary system. If, for instance, the secondary system consists of a straight run, by doing this we may use a wire with four times the impedance that would be required if the transformer were at one end, or with a given wire, we may distribute four times the current for the same drop in voltage.

These observations also hold good in case a number of transformers are to feed a continuous main. If we double the number of transformers, we quadruple the capacity of our wires or divide the drop by 4, provided, of course, they are evenly spaced throughout.

When the secondary system finally reaches the network stage and, if we assume wires leading out from each transformer in four directions with an equal load in each, we should be able to do with wire of sixteen times the impedance of the first-considered case. There, is however, no great advantage in using such small wires, and at this stage large transformers are indicated. The whole network of wires is also interconnected so that current from any one transformer tends to distribute toward any part in which an area of low potential develops.

In order to facilitate calculations concerning secondary lines the following tables have been prepared. By their use, if we assume even distribution of current, and even distance between distributing points, the drop at any part can be easily determined. In the lower table, LXXXVI, we have given the impedances for one ampere of 100 feet of line at 60 cycles and of various sizes of wire and at various separations. In

the upper table, LXXXIV, are given multipliers with which to multiply these impedances. It is assumed that the secondary line extends over a certain number of poles, and that at each of these poles a certain number of amperes are taken off. In order to use this table we select the horizontal line pertaining to the number of poles covered by the line, and in it select the number found where the vertical line pertaining to the pole at which we wish to determine the drop, crosses it. Multiplying this number by the current assumed to be taken off at each pole and by the impedance of the wire, we obtain the drop in voltage at this pole.

Example: We have a line extending over six poles (100 feet apart) and wish to find the drop at the third pole. We find the number 15 where the two lines cross; our wire is No. 1 and the separation 36 inches, while the current at each pole is 5 amperes; we have then for our drop $15 \times 0.036 \times 5 = 2.7$ volts.

In case we wish to determine the smallest wire that can be used under similar circumstances or conditions, we use the formula

$$Z = \frac{V}{IK}$$

in which Z is the impedance of the wire to be used, V the volts to be lost, I the current and K a number selected from the table as explained above.

Values of $\frac{V}{IK}$ have been calculated for all of the figures given in Table LXXXIV, and in order to find the smallest wire to deliver any amperage considered over any number of poles given, and at the desired loss, it is but necessary to follow the horizontal line pertaining to the proper constant K until it crosses

the vertical line pertaining to the amperes to be transmitted, and at this place we find the impedance of the wire, which will give us the drop of 2.7 volts. By referring the impedance to the table of impedances we can then select the proper size of wire. These tables enable us to make trial calculations very rapidly, and we can thus easily determine the most economical arrangement of conductors and transformers.

Example: Suppose we have twelve poles spaced 100 feet apart, and at each pole 5 amperes are to be used, while the drop must nowhere be greater than 2.2 volts. Is it cheaper to feed this line with one large transformer or with two small ones? Placing the large transformer at about the center, we have six poles on one side and five on the other. In table LXXXIV for the sixth pole we find the constant 21, and in table LXXXV, where the line pertaining to this constant crosses with that pertaining to 5 amperes, we find the impedance 0.021. Looking up table LXXXVI for a corresponding impedance under 12-inch separation, we find 0.022 as the nearest, and that a 0000 wire is needed to come that near to our purpose. On the other side of the transformer we have only five poles, and the constant for this is 15, which in the same way we find requires an impedance of 0.029 or a No. 0 wire. Making the calculations for two transformers, and for a continuous main, we may use the constant for the third pole, which is 6. Looking this up as before, we find an impedance of 0.07, which indicates a No. 5 wire continuous main for us. In order to find which is the cheapest we must now balance 1,100 feet of No. 5 wire and two 30-ampere transformers against 600 feet of 0000 wire plus 500 feet of No. 0, plus one 60-ampere transformer.

Tables for calculating the most economical arrangement of transformers and conductors.

TABLE LXXXIV

Number of poles covered by line	Transformer pole not counted. 1st Pole	2nd	3rd	4th	5th	6th
1	1					
2	2	3				
3	3	5	6			
4	4	7	9	10		
5	5	9	12	14	15	
6	6	11	15	18	20	21

TABLE LXXXV

Showing Values of $\frac{V}{IK}$

Constants K	Amperes 1	2	3	4	5	6	7	8	9	10	12	15
1	2.20	1.10	.733	.550	.440	.367	.314	.275	.244	.220	.183	.147
2	1.10	.550	.366	.275	.220	.183	.157	.138	.122	.110	.091	.073
3	.733	.366	.244	.183	.147	.122	.104	.092	.081	.073	.061	.049
4	.550	.275	.183	.137	.110	.092	.078	.069	.061	.055	.046	.037
5	.440	.220	.146	.110	.088	.073	.063	.055	.049	.044	.037	.029
6	.366	.183	.122	.092	.073	.061	.052	.046	.041	.037	.030	.024
7	.314	.157	.105	.079	.063	.052	.045	.039	.035	.031	.026	.021
9	.244	.122	.081	.061	.049	.041	.035	.031	.027	.024	.020	.016
11	.200	.100	.067	.050	.040	.033	.029	.025	.022	.020	.017	.013
12	.183	.092	.061	.046	.037	.031	.026	.023	.020	.018	.015	.012
14	.157	.078	.052	.039	.032	.026	.022	.020	.018	.016	.013	.010
15	.147	.074	.049	.037	.029	.024	.021	.018	.016	.015	.012	.010
18	.123	.061	.041	.031	.025	.021	.018	.016	.014	.012	.010	.009
20	.110	.055	.037	.028	.022	.017	.016	.014	.012	.011	.009	.007
21	.105	.052	.035	.027	.021	.017	.015	.013	.012	.010	.009	.007

TABLE LXXXVI

Showing Impedance Per Run of 100 Feet; 60 Cycles.

B. & S.	Separation in Inches. ½	6	12	24	36	B. & S.	Separation in Inches. ½	6	12	24	36
8	.126	.127	.128	.128	.128	1	.026	.031	.033	.035	.036
6	.081	.082	.083	.083	.084	0	.021	.027	.029	.031	.033
5	.066	.068	.069	.070	.071	00	.017	.023	.026	.028	.030
4	.051	.054	.055	.056	.057	000	.014	.021	.024	.026	.028
3	.041	.044	.046	.047	.048	0000	.011	.019	.022	.025	.027
2	.032	.038	.040	.041							

An inspection of table LXXXVII will show that large transformers have a much higher all-day efficiency than small ones; for instance, by placing one 4-K.W. transformer in place of four of 1 K.W.'s, we raise the efficiency (assuming the full load to be used three hours per day) from .84 to .91. In addition to this we also gain some in capacity, for the greater the number of customers connected to a transformer the greater will be the diversity factor. If we have a large number of small residences connected to one transformer, we need provide only about one-fourth the capacity of the connected load, whereas if we have one transformer for each customer we should be called upon for nearly the whole connected capacity. This gain in capacity comes in to such a marked extent only as long as we are dealing with transformers which are about fully loaded by one customer. As soon as the number of customers on any transformer reaches about twenty, they can be served with a transformer capacity which a larger number will not materially improve. A transformer capacity of one-fourth of the connected load will be sufficient for residence or flat lighting, but for stores, churches, and theatres a special study should be made as to what the maximum load of each is, and whether they are likely to occur at the same time.

The use of larger transformers effects a saving in cost of transformers and in operating expenses, but entails a greater outlay for conductors, and to find which is the more economical we must balance the increased cost against the saving, and the most economical arrangement will be that in connection with which the value of the energy lost equals the interest on the investment of capital that must be made to save it. This must be found by trial calculations, and the various tables given will facilitate the calculations. It will, however, seldom be necessary to make such

calculations, for in the first place the regulation of incandescent lamps limits us to a drop of about 2 volts, which alone requires the use of comparatively large wires; in the second place very low efficiency comes in only where the transformers are idle a large part of the time. This condition, even with low efficiency, causes only a nominal loss of power.

TABLE LXXXVII

Table Showing All Day Efficiency of Various Commercial Sizes of Transformers Used for Various Hours Per Day.

Equivalent Full Load Hours Per Day.

K.W.	1	2	3	6	9	12	18	24
1	.66	.78	.84	.89	.92	.93	.94	.96
1½	.70	.81	.86	.90	.93	.94	.96	.96
2	.72	.84	.88	.93	.94	.95	.96	.96
3	.77	.86	.90	.94	.95	.96	.96	.97
4	.79	.87	.91	.94	.95	.96	.96	.97
5	.81	.88	.92	.95	.95	.96	.96	.97
7½	.82	.90	.92	.95	.96	.97	.97	.97
10	.83	.90	.93	.96	.96	.97	.97	.97
15	.85	.91	.93	.96	.97	.97	.97	.98
20	.86	.91	.94	.96	.97	.97	.97	.98
25	.87	.92	.94	.96	.97	.97	.97	.98
30	.87	.93	.95	.96	.97	.97	.97	.98
40	.88	.93	.95	.96	.97	.97	.97	.98
50	.89	.94	.96	.97	.98	.98	.98	.98

Trolley Lines.—Trolley wires range in size from 0 to 0000; No. 0 is seldom used and 00 and 0000 are the most used.

Standard voltages d-c. are 600 and 1,200; a-c., 3,300, 6,600, and 11,000. A trolley system usually consists of feeders, trolley, and track return. The track return is often reinforced with negative feeders, and negative boosters are also used. (See also *Electrolysis.*)

The height of trolleys ranges from about 15 to 22 feet above the street; 22 feet is about the minimum allowed above tracks.

Trolley sections range from a few hundred yards to several miles in length; heavy traffic zones are usually fitted with short sections. Poles range from 30 to 40 feet in length, and wooden poles usually have 7-inch tops. The rake of poles varies from 4 to 12 inches, according to nature of soil.

There are various ways of trolley wire connections.

The trolley may be run alone; it may be reinforced by feeders, trolley and feeders being in parallel, or

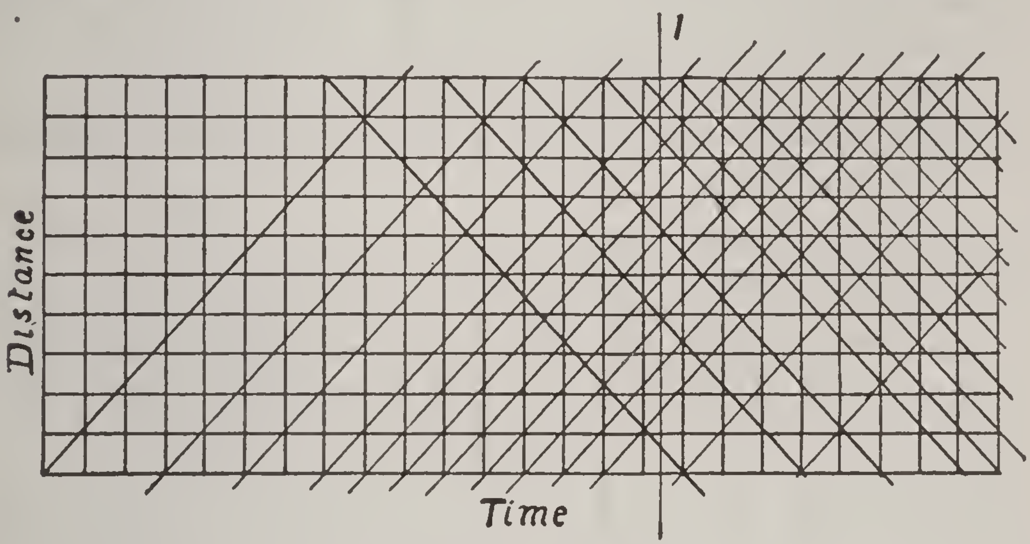


Figure 31.—Train Sheet.

it may be cut in sections, each section being fed by its own feeder. Alternating current systems do not usually have any secondary feeders. The drop allowed in d-c. systems ranges from 10 to 25 per cent; for a-c. systems it is 5 to 10 per cent.

The current used at any point can be approximately determined by use of the "train sheet" illustrated in Figure 31. The height of the figure represents the length of the road or of any part of it to be considered. The width of it may represent the length of time during which the load is to be determined.

For each car, or train, entering a section of trolley, draw a line beginning with the time the car enters

the section at the bottom and to meet the time point at the top at which it leaves that section. Draw lines beginning at the top of the figure in the same manner for all cars moving in the opposite direction. These lines will then cross, and to find the load on this section at any desired time, it is only necessary to draw an ordinate such as 1 at that point and count the number of car lines this crosses. This will give the number of cars fed over this section of trolley at that time, and the maximum current used can be easily determined.

TABLE LXXXIX

Table Showing Drop in Voltage Per 100 Amperes for Distance Given.

	Feet				Miles				
B. & S.	1,000	2,000	3,000	4,000	1	2	3	4	5
0	11.9	23.8	35.7	47.6	62.8	125.6	188.4	251	314
00	9.44	18.9	28.3	37.8	49.8	99.6	149.	199	249
000	7.48	15.0	22.4	29.9	39.5	79.0	118.	158	198
0000	5.94	11.9	17.8	23.8	31.4	62.8	71.4	126	157
C. M.				D. C. Only.					
500000	2.513	5.0	7.5	10.5	13.26	26.5	39.8	53.0	66.3
1000000	1.256	2.51	3.7	5.0	6.63	13.3	19.9	26.6	33.2
2000000	0.628	1.26	1.88	2.51	3.31	6.6	10.0	13.2	16.6
3000000	0.419	0.84	1.26	1.67	2.21	4.4	6.6	8.8	11.0
4000000	0.315	0.63	0.95	1.26	1.65	3.3	5.0	6.6	8.3
5000000	0.251	0.50	0.75	1.00	1.33	2.65	4.0	5.3	6.6

TABLE LXXXX

Table Showing P.D. on Return for Distances Above.

Wt. of Rails Per Yard. 2 Rails Used.									
40	1.23	2.46	3.69	4.92	6.5	13.0	19.5	26.0	32.5
45	1.09	2.18	3.27	4.36	5.8	11.6	17.4	23.2	29.0
50	0.98	1.96	2.94	3.92	5.2	10.4	15.6	20.8	26.0
60	0.81	1.62	2.43	3.24	4.3	8.6	12.9	17.2	21.5
70	0.70	1.40	2.10	2.80	3.7	7.4	11.1	14.8	18.5
80	0.61	1.22	1.83	2.44	3.2	6.4	9.6	12.8	16.0
90	0.55	1.10	1.65	2.20	2.9	5.8	8.7	11.6	14.5
100	0.49	0.98	1.47	1.96	2.6	5.2	7.8	10.4	13.0
110	0.45	0.90	1.35	1.80	2.4	4.8	7.2	9.6	12.0

The copper loss calculations are based on resistivity of hard drawn copper at 65° C 149° F.

Rails are supposed to be standard and of specific resistance of 10 times that of copper.

The losses in return circuit will be less than indicated because part of current returns through piping and earth.

The combined drop in conductors and rails in parallel is

equal to $\dfrac{1}{\frac{1}{d}+\frac{1}{d^1}+\frac{1}{d^2}}$ where d, d^1, d^2, etc., represent the drop in the different conductors.

The impedance of the rails at 25 cycles is said to be from 6 to 7 times as high as the ohmic resistance.

Impedance of trolley=1.5 times ohmic resistance.

Tables LXXXIX and LXXXX have been especially prepared to facilitate calculations concerning drop in trolley circuits. Every trolley circuit consists of three elements: trolley proper, its feeders and the track return, and in order to effect distribution economically, it is necessary to consider all of these separately.

The upper part of table LXXXIX gives the drop in voltage caused by the trolley proper, and the lower part that caused by feeders, either overhead to reinforce trolley or underground to help out track rails, and table LXXXX the drop caused by the iron rails. The calculations have not been carried out for a-c. because the circuits used for this method of transmission differ materially from d-c. systems. In a-c. systems the ground return may be considered as made up of a number of comparatively short sections, the current returning not to the central station but to its transformer. This is also true of the trolley. With energy distributed at 25 cycles, the drop caused by the rails will be about 6.5 times as great as for d-c. and that in the trolley about 1.5 times. The drop caused by

trolley and feeders, when they are in parallel, is equal to the reciprocal of the sum of the reciprocals of their lines. This is also the case with track rails and their reinforcement.

As far as these are used in series the various losses must be added.

The use of the tables can perhaps be best made clear by an example.

Example: The train sheet shows that 1,200 amperes will be required on a certain section of trolley one mile long and fed in the center by a feeder two miles long. The loss at far end of trolley must not exceed 15 per cent of the voltage, which is 600. The rails weigh 100 lbs. per yard, and the difference in potential between any two points must not exceed 5 volts. What size of feeder and reinforcement of track rails will be necessary?

Table LXXXIX shows that a 0000 trolley wire will cause a drop of 31.4 volts in one mile per 100 amperes. Our trolley is fed in the center and must be considered one-half mile long; each half carries half of the current, viz., 600 amperes; therefore, the drop caused by a 0000 trolley will be six times the drop in half a mile, or, according to our table, 94.2 volts. This alone is more than 15 per cent of our voltage, 600, hence we must divide our trolley into shorter sections. Making two sections out of the same length, or feeding it in two places, will give us a loss equal to 300 amperes for one-fourth mile, or just one-fourth of what we had before, viz., 23.6 volts lost in trolley.

We have next to deal with the size of feeder, and are allowed a loss of slightly over 60 volts in it. The loss in feeders two miles long is given in table LXXXX, and we may use any feeder the loss of which, multiplied by 12, does not exceed 67 volts.

12 times 6.6 equals 79.2, and is the loss caused by a 2,000,000-cm. cable. This we must not use, but the next larger one will give us a loss of only 52.8, and this, added to the trolley loss, makes a total of 76.4 volts. If it is desired to lose the full 90 volts a smaller trolley wire may now be considered.

The loss in one mile of 100-lb. track is 2.6 volts per 100 amperes, which makes 31.2 for 1200; a 5,000,000-cm. cable causes a drop of twelve times 1.33, or 15.96 volts. The drop caused by both in parallel will be the reciprocal of the sum of the reciprocals. By the table of reciprocals we find the reciprocal of 31.2 is, roughly, 0.032051, and that of 15.96 is 0.062500. Adding these, we have 0.094, approximately. The number corresponding to this from the same table is 10.6, which is more than two times too high. Let us now consider the use of two 5,000,-000 cables. The drop in the cables will be just half of what it was before, or about 8. The reciprocal of 8 is 0.01250; this added to 0.032 gives us 0.157, and the number corresponding to it is about 6.4. This is still above what we require, but it must be borne in mind that not all of the current returns over the rails and negative feeders, hence, this will give us about the right p.d. The loss in trolley lines, track, and feeders can be lessened very much by increasing the number of substations from which they are fed, and the most economical arrangement can be determined by the same calculations laid out for locating transformers.

Underground Construction.—Underground conductors are usually lead encased and as the lead is not very strong it is best to run the conductors in some form of conduit which protects them and facilitates removal in case of trouble. These conduits usually consist of some kind of clay, concrete or fiber, and their heat conductivity is generally not as good as

that of moist earth. Conduits arranged as shown in Figure 32 carry away more heat than those shown at Figure 33, but if there are many of them they also require more trench area.

All conduits should be arranged to drain, and at suitable intervals should be provided with splicing chambers. If space between them is to be filled with concrete they must be anchored to prevent floating.

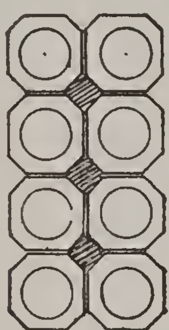


Figure 32.

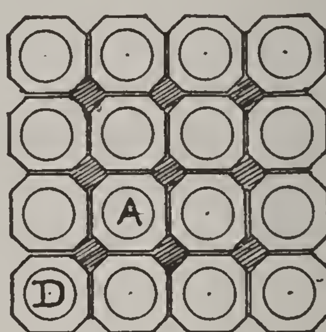


Figure 33.

Underground Ducts.

The following tables and information is taken from Handbook No. 17 of the Standard Underground Cable Co. (Copyright by Standard Underground Cable Co., 1906).

Recommended Current Carrying Capacities for Cables, and Watts Lost per Foot, for each of four equally loaded single conductor paper insulated lead covered cables, installed in adjacent ducts in the usual type of conduit system where the initial temperature does not exceed 70° F. (21.1° C.), the maximum safe temperature for continuous operation being taken as 150° F. (65.5° C.).

TABLE LXXXXI

Size B. & S.	Safe Current in Amp.	Watts Lost Per Ft. at 150° F.	Size B. & S. or C. M.	Safe Current in Amp.	Watts Lost Per Ft. at 150° F.	Size Circular Mils.	Safe Current in Amp.	Watts Lost Per Ft. at 150° F.
14	18	0.97	2	125	2.77	900000	650	5.71
13	21	1.03	7	146	3.00	1000000	695	5.86
12	24	1.09	0	168	3.23	1100000	740	6.01
11	29	1.15	00	195	3.46	1200000	780	6.13
10	33	1.25	000	225	3.69	1300000	820	6.25
9	38	1.39	0000	260	3.92	1400000	857	6.37
8	45	1.53	300000	323	4.22	1500000	895	6.49
7	53	1.67	400000	390	4.61	1600000	933	6.61
6	64	1.85	500000	450	4.91	1700000	970	6.73
5	76	2.08	600000	505	5.16	1800000	1010	6.85
4	91	2.31	700000	558	5.36	1900000	1045	6.97
3	108	2.54	800000	607	5.56	2000000	1085	7.09

Assuming that unity (1.00) represents the carrying capacity of single-conductor cables, the capacity of multi-conductor cables would be given by the following:

2 Cond., flat or round form, 0.87; concentric form, 0.79.

3 Cond., triplex form, 0.75; concentric form, 0.60.

The following experiment on duplex concentric cable of 525,000 c.m. indicates clearly the danger in subjecting this type of cable to heavy overloads of even short duration. The cable was first heated up by a current of 440 amperes for five hours. An overload of 50 per cent was then applied, the results in degrees Fahrenheit above the surrounding air being as follows:

Time from start	0 min.	15 min.	30 min.	45 min.	60 min.	90 min.
Inner condr...	70°	84°	98°	111°	123°	142°
Outer condr...	55°	65°	76°	85°	94°	108°
Lead cover...	31°	35°	40°	45°	49°	57°

As it is the final temperature reached which really affects the carrying capacity, the initial temperature of surrounding media must be taken into account. If, for instance, the conduit system parallels steam or hot water mains, the temperature of 150 F., which we have assumed in the table to be the maximum for safe continuous work on cables, will be reached with lower values of current than would otherwise be the case; and as 70 is the actual temperature we have assumed to exist in the surrounding medium prior to loading the cables, any increase over 70 must be compensated for by reducing the current.

For rough calculations it will be safe to use the following multipliers to reduce the current carrying capacity given in table LXXXXI to the proper value for the corresponding initial temperatures.

Initial temp. F.	70°	80°	90°	100°	110°	120°	130°	140°	150°
Multipliers ...	1.00	0.93	0.86	0.78	0.70	0.60	0.48	0.34	0.00

When a number of loaded cables are operating in close proximity to one another, the heat from one radiates, or is carried by conduction, to each of the others, and all are raised in temperature beyond what would have resulted had only a single cable been in operation. And if the cables occupy adjacent ducts in a conduit system of approximately square cross-section laid in the usual way, the centrally located cable or the one just above the center in large installations (*A* in Figure 32) will reach the highest temperature. This is equivalent to saying that its current carrying capacity is reduced and while this reduction does not amount to more than 12 per cent (as compared with the cable most favorably located, *D*, Figure 32) in the duct arrangement given it may easily assume much greater proportions where a large number of cables are massed together.

Assuming that not more than twelve cables, arranged as shown in Figure 32, can be used, the average carrying capacity may be taken as the criterion for proper size of conductor, and for cables of a given type and size the carrying capacities of all cables, even though placed in adjacent ducts, will be represented by the following figures, taking unity as the average carrying capacity of four cables. (See Table LXXXXI.)

Number of cables	2	4	6	8	10	12
Multiplier	1.16	1.00	0.88	0.79	0.71	0.63

Recommended Power Carrying Capacity in Kilowatts of Delivered Energy.—The tables below are based on the carrying capacities of cables as given in Table LXXXXI. A power factor of unity was used in the calculations and hence the values found in the lower table are correct for direct current. For alternating current the kilowatts given must be multiplied by the power factor of the delivered load.

Units.—Synopsis of units and symbols in general use.

Unit	Name	Symbol	Defining Equation: Direct Current	Defining Equation: Alternating Current
Electromotive force	Volt	E, e	I R	I Z
Current	Ampere	I, i	$E \div R$	$E \div Z$
Resistance	Ohm	R, r	$E \div I$	$\sqrt{Z^2 - X^2}$
Power	Watt	P	E I	E I $\times$ p. f.
Impedance	Ohm	Z, z		$\sqrt{R^2 + X^2}$
Reactance	Ohm	X, x		$\sqrt{Z^2 - R^2}$
Inductance	Henry	L, l	$\Phi \div I$	
Capacity	Farad	C, c	$Q \div E$	$Q \div E$
Quantity	Coulomb	Q, q	I $\times$ time	I $\times$ time
Admittance	Mho	Y, y		$I - Z = \sqrt{G^2 + B^2}$
Conductance	Mho	G, g	$I \div R$	$R \div Z^2 = \sqrt{Y^2 - B}$
Susceptance	Mho	B, b		$X - Z^2 = \sqrt{Y^2 - G^2}$

TABLE LXXXII

Three Conductor, Three-Phase Cables.

Size in B. & S.	Volts. 1100	2200	3300	4000	6000	11000	13200	22000
	Kilo-Watts.							
6	92	183	275	333	549	915	1098	1831
5	109	217	326	395	652	1087	1304	2174
4	130	260	390	473	781	1301	1562	2603
3	154	309	463	562	927	1544	1854	3089
2	179	358	536	650	1073	1788	2145	3575
1	209	418	626	759	1253	2088	2506	4176
0	240	481	721	874	1442	2402	2884	4805
00	279	558	836	1014	1674	2788	3347	5577
000	322	644	965	1172	1931	3217	3862	6435
0000	372	744	1115	1352	2231	3717	4462	7435
250000	413	827	1240	1503	2480	4132	4960	8264

Single Conductor Cables, A. C. or D. C.

Size in B. & S.	Volts. 125	250	500	1100	2200	3300	6600	11000
	Kilo-Watts.							
6	8.0	16.0	32	70	141	211	422	704
5	9.5	19.0	38	84	167	251	502	836
4	11.4	22.8	45	100	200	300	601	1001
3	13.5	27.0	54	119	238	356	713	1188
2	15.6	31.2	62	138	275	413	825	1375
1	18.3	36.5	73	161	321	482	964	1606
0	21.0	42.0	84	185	370	554	1109	1848
00	24.4	48.8	97	215	429	644	1287	2145
000	28.1	56.3	113	248	495	743	1485	2475
0000	32.5	65.0	130	286	572	858	1716	2860
300000	40.4	80.8	162	355	711	1066	2132	3553
400000	48.8	97.5	195	429	858	1287	2574	4290
500000	56.3	112.5	225	495	990	1485	2970	4950
600000	63.1	126.3	253	556	1111	1667	3333	5555
700000	69.8	139.5	279	614	1228	1841	3683	6138
800000	75.9	151.8	304	668	1335	2003	4006	6677
900000	81.3	162.5	325	715	1430	2145	4290	7150
1000000	86.9	173.8	348	764	1529	2294	4587	7645
1100000	92.5	185.0	370	814	1628	2442	4884	8140
1200000	97.5	195.0	390	858	1716	2574	5148	8580
1400000	107.1	214.3	429	943	1885	2828	5656	9427
1500000	111.9	223.8	448	985	1969	2954	5907	9845
1600000	116.6	233.3	467	1026	2053	3079	6158	10263
1700000	121.3	242.5	485	1067	2134	3201	6402	10670
1800000	126.3	252.5	505	1111	2222	3333	6666	11110
2000000	135.6	271.3	543	1194	2387	3581	7161	11935

Ventilation.—Ventilation for the purpose of providing a certain quantity of fresh air to occupants of rooms or shops requires the apparatus to be in use continuously while the rooms are occupied, regardless of temperature. Where it is provided mainly to carry off surplus heat, it is used only in warm weather. The capacity in such cases must be sufficient to take care of the hottest weather.

The quantity of air moved by any fan varies directly as the speed, but the power required to run the fan varies as the cube of the speed. The net result is that the cost of moving different volumes of air by any given fan varies about as the square of the speed at which the fan must operate to move it. This is the theoretical relation, but this is somewhat disturbed by the difference in efficiency of large and small motors operating at various speeds. Owing to the above facts it is often a difficult task to decide whether it is more profitable to install a small, cheap fan and run it at a high rate of speed, or to provide a more expensive one and operate it at a lower cost per unit of air moved. Which is the more profitable in the long run depends upon the number of hours per year the fan is to be used at its various speeds. In any case the most economical ventilator will be the one in connection with which the cost of energy saved per year will equal the interest charge upon the investment of capital necessary to provide it in place of the cheapest fan which can do the work. The following tables are taken from publications of the American Blower Co. and give all the necessary data for comparison of various fans. In order to find the most economical fan select the smallest fan capable of moving the requisite amount of air and note the K. W. necessary to run it (divide H. P. given by 1.3). Next select some larger fan and note the K. W. necessary to move the same volume of air with this fan and sub-

tract it from the first. The next step is to find the value of the annual saving, by multiplying the number of hours per year this power is used by the rate per K. W. Having found this, if we divide it by the rate of interest applicable, we shall obtain the sum of money which we can afford to spend to substitute this fan in place of the smallest one we were considering. The rate of interest by which we must divide is determined by the number of years the installation is to remain in use and is as follows:

One year, 1.06 per cent; 2 years, .57; 3 years, .40; 4 years, .32; 5 years, .27; 6 years, .24; 7 years, .21½; 8 years, .20; and 9 years, .18¾.

We have now the following formula by which we can determine the amount of capital which can with profit be invested in a larger fan:

$$C = \frac{\text{K. W.} - k.\,w. \times h \times r}{\%}$$

where C = capital to be invested; K. W. $- k.\,w.$ = the saving in energy per hour, and h and r = the number of hours per year and rate per K. W. hour of energy.

In case the fan is used intermittently at various speeds the calculations should be made accordingly, since the power required at high speeds is much greater than at low speeds. The capacity of a fan used only to provide a sufficient quantity of fresh air is best determined by allowing from 30 to 50 cubic feet of air per minute for each adult, and from 20 to 35 for each child. In special places such as hospitals this quantity is often doubled. The maximum quantities given will secure ample ventilation for all ordinary persons. In public places such as toilet rooms, waiting rooms, etc., it is customary to require from three to six changes of air per hour.

TABLE LXXXXIII

"Ventura" Disc Ventilating Fans.

General Capacity Table.—American Blower Co.

Capacities, Speeds and Horse Powers with Unobstructed Inlet and Discharge.

No. of Fan		Velocity of Air in Feet per Minute. 600	900	1200	1500	1800	2100
	Cu. Ft. Per Min..	950	1420	1895	2370	2840	3320
3	Pres. Ins. W. G..	.0225	.055	.09	.1406	.2025	.2755
	R. P. M.........	625	980	1255	1565	1880	2190
	H. P.	.0097	.036	.079	.153	.265	.42
	C. F. M.........	1620	2430	3240	4050	4860	5670
4	Pres. ins........	.0225	.055	.09	.1406	.2025	.2755
	R. P. M.........	470	735	945	1175	1410	1645
	H. P............	.0168	.062	.13	.262	.455	.72
	C. F. M.........	2500	3750	5000	6250	7500	8750
5	Press. Ins.......	.0225	.055	.09	.1406	.2025	.2755
	R. P. M.........	375	585	755	938	1125	1310
	H. P............	.026	.095	.207	.405	.701	1.10
	C. F. M.........	3560	5350	7125	8900	10700	12500
6	Press. Ins.......	.0225	.055	.09	.1406	.2025	.2755
	R. P. M.........	315	492	632	786	945	1100
	H. P............	.037	.136	.295	.575	1.00	1.59
	C. F. M.........	4800	7200	9600	12000	14400	16800
7	Press. Ins.......	.0225	.055	.09	.1406	.2025	.2755
	R. P. M.........	268	419	537	669	803	936
	H. P............	.05	.182	.398	.776	1.345	2.13
	C. F. M.........	6250	9375	12500	15600	18750	21850
8	Press. Ins........	.0225	.055	.09	.1406	.2025	.2755
	R. P. M.........	234	366	470	584	702	817
	H. P............	.065	.237	.516	1.01	1.75	2.77
	C. F. M..........	7875	11800	15700	19650	23600	27500
9	Press. Ins........	.0225	.055	.09	.1406	.2025	.2755
	R. P. M.........	209	326	419	521	626	730
	H. P............	.082	.30	.65	1.27	2.20	3.48

TABLE LXXXXIV

Capacities, Speeds and Horse Powers with Resistance of Average Piping System.

No. of Fan		Velocity of Air in Feet per Minute.					
		600	900	1200	1500	1800	2100
	Cu. Ft. Per Min..	950	1420	1895	2370	2840	3320
3	Press. Ins. W. G..	.06	.15	.24	.37	.53	.73
	R. P. M.........	716	1075	1435	1790	2150	2510
	H. P............	.022	.085	.18	.34	.59	.93
	C. F. M.........	1620	2430	3240	4050	4860	5670
4	Press. Ins........	.06	.15	.24	.37	.53	.73
	R. P. M.........	540	808	1075	1345	1615	1885
	H. P............	.037	.14	.30	.58	1.00	1.59
	C. F. M.........	2500	3750	5000	6250	7500	8750
5	Press. Ins........	.06	.15	.24	.37	.53	.73
	R. P. M.........	430	644	860	1075	1288	1500
	H. P............	.057	.21	.46	.90	1.54	2.45
	C. F. M.........	3560	5350	7125	8900	10700	12500
6	Press. Ins........	.06	.15	.24	.37	.53	.73
	R. P. M.........	361	540	720	900	1080	1260
	H. P............	.082	.30	.65	1.27	2.20	3.50
	C. F. M.........	4800	7200	9600	12000	14400	16800
7	Press. Ins........	.06	.15	.24	.37	.53	.73
	R. P. M.........	307	460	614	767	920	1075
	H. P............	.11	.40	.88	1.71	2.96	4.69
	C. F. M.........	6250	9375	12500	15600	18750	21850
8	Press. Ins........	.06	.15	.24	.37	.53	.73
	R. P. M.........	268	402	535	670	803	940
	H. P............	.143	.53	1.14	2.23	3.85	6.10
	C. F. M.........	7875	11800	15700	19650	23600	27500
9	Press. Ins........	.06	.15	.24	.37	.53	.73
	R. P. M.........	239	358	477	597	716	835
	H. P............	.18	.67	1.43	2.80	4.84	7.68

Pressures noted are static pressures.

Where it is desired to reduce temperature or remove steam, etc., we must proceed to find the necessary capacity in another way. If we remove all of the heated air in a room and replace it with air from the outside in the same length of time required to heat it, we shall reduce the temperature by one-half the difference between that of the air in the room and the air brought in. From this fact we can deduce the following method for determining the amount of air which must be taken out of a room in order to lower its temperature by any desired amount. Before the room has attained its full temperature place one or more thermometers at representative locations and note the temperature rise for any convenient length of time, but be sure that you are observing the maximum or general temperature rise which is to be ventilated for. By providing ventilator capacity to exhaust all of the air in the room one or more times in the same length of time in which the rise took place we shall reduce it according to the following tabulation which shows the number of degrees F. which the room temperature will be above the outside temperature with the number of changes taking place as given at the left in column 0. The column 0 is correct only when the room is so tightly closed that there is no natural ventilation. Under the other columns, headed by 1, 2, 3, 4, and 5, are given the number of times the air must be changed to limit the temperature rise in room to the increases above the outside air as given in right hand section of table. Thus, if the increase in temperature allowed over the outside air is 30 degrees and the air is naturally changing three times we must change it twelve times to limit the rise to 5 degrees.

TABLE LXXXXV

Number of natural changes of air assumed.						Increase in degrees F. above outside air.							
5	4	3	2	1	0	5	10	15	20	25	30	35	40
10	8	6	4	2	1	2 1/2	5	7 1/2	10	12 1/2	15	17 1/2	20
15	12	9	6	3	2	1 1/4	2 1/2	3 3/4	5	6 1/8	7 1/2	8 3/4	10
20	16	12	8	4	3	5/6	1 2/3	2 1/2	3 1/3	4 1/6	5	5 5/6	6 2/3
25	20	15	10	5	4	5/8	1 1/4	1 7/8	2 1/2	3 1/8	3 3/4	4 3/8	5

Rule.—Determine difference in temperature between outer and inner air which is to be ventilated for, and trace down column headed by this temperature until the allowable temperature of inner over outer air is reached. Next estimate number of natural changes taking place during the time of previous test and in section of table at left headed by this number trace down to same horizontal line in which the permissible temperature was found. At this point the necessary number of changes in air will be found. These changes must take place in the same length of time in which the temperature rise took place.

If there is a temperature rise accompanied by natural ventilation the reductions in temperature given in Table LXXXXV, column 0, can be obtained only by doubling the number of changes taking place during the time that the rise in temperature was going on.

Suppose, for instance, that a certain temperature rise takes place in an hour while during the same time the air is naturally changing ten times. The starting of the ventilator, if of sufficient capacity, immediately

ends all natural ventilation because every former outlet for air now becomes an inlet and all air passes through the fan. The number of changes which were naturally taking place now count for nothing and to reduce the temperature by one-half we must provide ten more changes per hour, *i.e.*, change the air by means of the fan twenty times to obtain the effect of one change as given in column 0. Thus to find the number of changes necessary to obtain the effects given in the table in column 0 we must use the formula $c=(a \times b)+a$, where c=the number of changes that must be made; a=the number of natural changes taking place, and b=the figure in column 0 which corresponds to the desired rise above the outside air at the difference in temperature.

Example.—The increase in temperature in a certain room is 10 degrees above that of the outside air and is to be limited to $2\frac{1}{2}$ degrees; the dimensions of the room are $100 \times 20 \times 12$, while the natural change of air is assumed to be about three times per hour. What must be the capacity of the ventilating fan? Tracing down in Table LXXXXV under 10 degrees to where $2\frac{1}{2}$ is found, and then in the horizontal line to the left, to column pertaining to three changes of air per hour, we find the number 9, which signifies that we must have capacity to change the air nine times per hour, and since the room contains 24,000 cubic feet we must select a fan which can move 3,600 cubic feet per minute.

Practical Hints.—Place ventilators at end of room opposite to where most of the air enters or so that all disagreeable air is nearest to the fan. Protect fan against wind blowing into it. Avoid noise by selecting large fans to operate at low speeds. Air in motion does not feel as warm as stationary air. It is best to provide a separate fan for kitchen ranges, etc., and attach it directly to hoods placed over such apparatus.

In wide or square rooms provide several ventilators so as to secure a more uniform movement of air over the whole space. If fan capacity is small compared to size of room and cooling is the only consideration it is best to blow air into the room. An exhaust fan which does not change the air oftener than it is naturally changing has little effect. Even in well constructed places the air is supposed to change itself once per hour at least.

Voltage Regulation.—In a network of wiring the regulation is always fairly good because a heavy demand at any point immediately causes current from all sides to rush in. The drop at feeder ends can be easily compensated for if they are all of the same length. If they are not of the same length they should be divided into groups of the same length and each group separately regulated. For d. c. work individual feeder regulators waste too much energy to be considered except with very short lines.

In long lines a booster is often installed. To determine whether it is profitable to install a booster we must compare its cost and the losses due to its operation, with the cost of increasing the size of conductors proportionately and the losses incident to the improved lines. Obviously this depends upon the length of the line, and the drop which may be allowed. Determine investment for booster, interest and depreciation and cost of operation and losses. This amount can be saved by the installation of proper feeders, and if we can obtain the larger feeders by an investment of capital upon which the above sum will be the proper interest it will not be profitable to install the booster.

For a. c. work individual feeder regulators are much used, and as they waste comparatively little energy, they may be used in each feeder and all feeders connected to a common line. Such regulators may be

arranged either to boost or choke. For low tension work, either a. c. or d. c., pressure wires are often run from the end of feeder back to switchboard to indicate the pressure at feeder end. The same object is also attainable by line drop compensators, or if the size and length of line be known the drop at the far end or any other point may be calculated from the number of amperes.

The following table (LXXXVI) is provided to assist in making the necessary calculations for the setting of a. c. line drop compensators, and also to determine the drop in voltage occurring at any part of the line so that the voltage at the station may be raised correspondingly.

To find the drop in voltage we may use the formula $IZ \times d$; in which I is the current in amperes; Z the impedance as given in the table for various sizes of wire and separation, and d the number of 1,000 feet of line.

For line compensators it is necessary to find the percentage of the reactive, and ohmic drop. The same formula may be used substituting X or R for Z and dividing the result by the transmission voltage. This will give the percentage according to which the two sections of the compensator must be set. See detail instructions sent out with compensators. The values of Z, R and X are for 1,000 feet of wire. A single phase installation can be served by a single compensator, but then the drop will be double that given, or for 2,000 feet instead of 1,000 feet of wire. The same may be said of a two phase installation which is served by two compensators, but in two phase three wire, or in three phase systems, a compensator must be installed in each wire, and a four wire three phase system requires four, so that in connection with these systems the value given in the table need not be doubled.

TABLE LXXXXVI

Table Showing Resistance, Reactance and Impedance of 1,000 Feet of Wire of Sizes Given and at Various Separations.

		Separation of Wires in Inches.											
		12		24		36		48		60		72	
B. & S.	R	X	Z	X	Z	X	Z	X	Z	X	Z	X	Z
8	.627	.126	.640	.142	.640	.151	.640	.157	.640	.163	.640	.167	.640
6	.397	.120	.415	.136	.415	.145	.420	.152	.420	.157	.420	.161	.420
5	.314	.118	.345	.134	.350	.143	.355	.150	.357	.155	.360	.159	.362
4	.250	.115	.275	.131	.280	.140	.285	.147	.290	.152	.292	.156	.294
3	.198	.112	.230	.128	.235	.137	.240	.144	.245	.150	.248	.153	.251
2	.157	.110	.190	.126	.200	.135	.205	.141	.212	.147	.215	.151	.217
1	.126	.107	.165	.123	.175	.132	.180	.139	.187	.144	.191	.148	.194
0	.100	.104	.145	.120	.155	.129	.165	.136	.169	.141	.173	.145	.176
00	.079	.102	.130	.118	.140	.127	.150	.133	.156	.139	.159	.143	.162
000	.063	.099	.120	.115	.130	.124	.140	.131	.145	.136	.149	.140	.153
0000	.050	.096	.110	.112	.125	.122	.135	.128	.138	.133	.140	.137	.146

Weights of Materials in Pounds *(Approximate)*.—
Aluminum, cu. ft., 167; cu. in., 0.095. For wires, see tables.
Antimony, cu. ft., 418; cu. in., 0.242.
Asphaltum, cu. ft., 84; gal., 11.2.

Bismuth, cu. ft., 612; cu. in., 0.354.
Brass, cu. ft., 522; cu. in., 0.302.
Brick, cu. ft., 119; per thousand, 4500.
Bronze, cu. ft., 537; cu. in., 0.311.

Cement, loose, cu. ft., 88; bu., 95.
Charcoal, cu. ft., 25; bu., 27.
Coal, anthracite, piled loose, cu. ft., 52; bu., 56.
" bituminous, piled loose, cu. ft., 50; bu., 54.
Coke, piled loose, cu. ft., 27; bu., 29.

Concrete, cu. ft., 150; cu. yd., 4050.
Copper, cu. ft., 555; cu. in., 0.321. For wires, see tables.
Cork, cu. ft., 15.6.
Crushed Stone, cu. yd., 2700.

Earth, cu. ft., 109; cu. yd., 2943.

Glass, cu. ft., 165.
Gold, cu. ft., 1225; cu. in., 0.709.
Gravel, cu. ft., 119; cu. yd., 3213.

Ice, cu. ft., 56; cu. yd., 1512.
Iridium, cu. ft., 1400; cu. in., 0.81.
Iron, cu. ft., 490; cu. in., 0.225. For wires, see tables.

Lead, cu. ft., 709; cu. in., 0.41.
Limestone, cu. ft., 165; cu. yd., loose, 2700.
Loam, cu. ft., 78; cu. yd., 2106.

Mercury, cu. ft., 850; cu. in., 0.492.

Nickel, cu. ft., 540; cu. in., 0.312.

Oils, olive, gal., 7.6.
" cottonseed, gal., 8.0.
" linseed, gal., 7.8.
" turpentine, gal., 7.2.
" lard, gal., 7.9.
" whale, gal., 7.8.
" gasoline, gal., 5.7.
" petroleum, gal., 7.3.
" mineral lubricating, gal., 7.8.

Paper, cu. ft., 56.
Paraffine, cu. ft., 56; gal., 7.41.
Pitch, cu. ft., 67; gal., 8.9.

Platinum, cu. ft., 1340; cu. in., 0.718.
Porcelain, cu. ft., 150; cu. in., 0.087.

Salt, cu. ft., 60; gal., 8.04.
Sand, cu. ft., 105; cu. yd., 2835.
Silver, cu. ft., 653; cu. in., 0.377.
Slate, cu. ft., 184; cu. in., 0.109.
Sulphur, cu. ft., 125.

Tantalum, cu. ft., 1040; cu. in., 0.60.
Tar, cu. ft., 62.5; gal., 8.33.
Tin, cu. ft., 455; cu. in., 0.263.
Tungsten, cu. ft., 1175; cu. in., 0.68.

Water, plain, cu. ft., 62.5; gal., 8.33.
" sea, cu. ft., 79; gal., 10.3.

Wood,	ash,	cu. ft.,	46;	per 1000 ft.,	3850.
"	butternut,	"	28;	"	2330.
"	cedar,	"	38;	"	3165.
"	chestnut,	"	39;	"	3250.
"	cypress,	"	35;	"	2915.
"	elm,	"	36;	"	3000.
"	fir,	"	35;	"	2915.
"	hemlock,	"	27;	"	2250.
"	hickory,	"	55;	"	4600.
"	lignum vitae,	"	81;	"	6750.
"	mahogany	"	36;	"	3000.
"	maple,	"	50;	"	4560.
"	oak,	"	47;	"	3915.
"	pine, white,	"	25;	"	2275.
"	pine, yellow,	"	45;	"	3750.
"	poplar,	"	24;	"	2200.
"	redwood,	"	30;	"	2740.
"	spruce,	"	28;	"	2330.
"	walnut,	"	41;	"	3400.

Zinc, cu. ft., 420; cu. in., 0.243.

Contents of Barrels or Round Containers = average diameter squared × height × 0.7854.

If measurements are taken in inches

$$D^2 \times H \times 0.000454 = \text{cu. ft.}$$
$$D^2 \times H \times 0.0034 = \text{gal.}$$
$$D^2 \times H \times 0.000425 = \text{bu.}$$

If cubic contents are known in feet, multiply by 7.58 to obtain gallons, and by 0.936 to obtain bushels. To obtain cubic yards divide by 27.

Welding.—From 30 to 60 H. P. per square inch area of weld to be made are used. This is the power required to be delivered to welder. The greater the capacity the shorter will be the time required to make a weld. In some cases only a few seconds are required.

Wire Calculations.—This division contains the following tables:

A table of carrying capacities of copper and aluminum wires.

A table showing carrying capacities of different combinations of wires.

Table for determining the total wattage of groups of lamps or other devices usually rated in watts.

Tables for calculating the amperage per H. P. of motors at various efficiencies and power factors.

Tables showing maximum H. P. allowed on wires according to N. E. C. rules and carrying capacities.

Tables for determining proper size of wire for a certain loss in voltage; copper and aluminum wires, direct current, and 60 and 25 cycles.

Tables to facilitate determining the most economical conductors.

Various tables showing physical properties of copper, aluminum, copper clad, german silver and steel wires.

Tables showing outside diameters of wires and cables.

TABLE LXXXVIII

Table of Allowable Carrying Capacity of Wires.

B. & S. Gauge	Rubber Insulation Copper	Rubber Insulation Aluminum	Other Insulations Copper	Other Insulations Aluminum	Circular Mils
18	3	2	5	4	1624
16	6	5	10	8	2583
14	15	12	20	17	4107
12	20	17	25	21	6530
10	25	21	30	25	10380
8	35	29	50	42	16510
6	50	42	70	59	26250
5	55	46	80	67	33100
4	70	59	90	76	41740
3	80	67	100	84	52630
2	90	76	125	105	66370
1	100	84	150	126	83690
0	125	105	200	168	105500
00	150	126	225	189	133100
000	175	147	275	231	167800
0000	225	189	325	273	211600
Circular Mils					
200000	200	168	300	252	
300000	275	231	400	336	
400000	325	273	500	420	
500000	400	336	600	504	
600000	450	378	680	571	
700000	500	420	760	639	
800000	550	462	840	705	
900000	600	504	920	773	
1000000	650	546	1000	840	
1100000	690	580	1080	901	
1200000	730	613	1150	966	
1300000	770	646	1220	1024	
1400000	810	680	1290	1083	
1500000	850	714	1360	1142	
1600000	890	748	1430	1201	
1700000	930	781	1490	1251	
1800000	970	815	1550	1301	
1900000	1010	848	1610	1352	
2000000	1050	882	1670	1402	

Carrying Capacities of Different Combinations of Wires.—Owing to the relatively different radiating surface of wires of different sizes the carrying capacity per circular mil is not the same for all wires, and where wires of different gauge number are to be connected in parallel this must be taken into account. In the following table this is done and the carrying capacity of smaller wires at the current density allowed for the larger wires is given wherever the horizontal and vertical lines pertaining to any two wires cross. The number found at this place indicates the amperage the smaller wire will have with the larger wire fully loaded. The figures are based on the carrying capacities given by the National Electrical Code. To find the proper wire to reinforce another which has been overloaded: Select the horizontal line pertaining to the larger wire and follow along this line until a number about equal to the necessary additional amperes is found. At the head of the vertical column in which this number is found will be found the gauge number of the proper wire to be used.

TABLE LXXXXIX

Table Showing Combined Carrying Capacity of Different Wires—Rubber Insulation

Amps.	B.&S.	14	12	10	8	6	5	4	3	2	1	0	00	000	0000
15	14	15													
20	12	12	20												
25	10	10	15	25											
35	8	8	13	22	35										
50	6	7	12	20	31	50									
55	5	7	11	17	27	44	55								
70	4	7	11	18	28	45	55	70							
80	3	6	10	16	25	39	50	64	80						
90	2	5	9	14	22	35	45	56	71	90					
100	1	5	8	12	19	31	39	49	63	80	100				
125	0	5	7	12	19	31	39	49	62	77	98	125			
150	00	4	7	11	18	30	37	47	59	74	94	118	150		
175	000	4	6	10	17	27	34	43	54	69	87	108	138	175	
225	0000	4	7	11	17	28	35	44	56	76	89	112	141	178	225
275	300000		6	9	15	24	30	38	48	61	77	96	122	154	194
325	400000		5	8	13	21	26	33	43	54	68	85	109	137	172
400	500000		5	8	13	21	26	33	42	53	67	84	106	134	169

Other Insulations

Amps.	B&S.	14	12	10	8	6	5	4	3	2	1	0	00	000	0000
20	14	20													
25	12	15	25												
30	10	11	19	30											
50	8	12	19	31	50										
70	6	10	17	27	44	70									
80	5	10	16	25	40	64	80								
90	4	10	16	25	40	64	80	90							
100	3	7	12	19	31	50	63	80	100						
125	2	7	12	19	31	50	63	78	99	125					
150	1	7	11	18	29	47	59	74	94	118	150				
200	0	7	12	19	31	49	62	79	99	125	157	200			
225	00	7	11	17	28	44	56	70	89	112	141	178	225		
275	000	6	10	17	27	43	54	68	86	109	137	173	218	275	
325	0000	6	10	16	25	40	51	64	81	102	128	162	204	258	325
400	300000	5	8	14	22	35	44	55	70	88	112	140	177	223	282
500	400000	5	8	13	20	33	41	52	66	83	104	132	166	209	264
600	500000	5	8	12	20	31	40	50	63	80	100	127	160	202	255

TABLE C

Table for determining total wattage required for incandescent lamps or other devices usually rated in watts.

To find total wattage add all numbers found where lines pertaining to number of lamps and wattage of same cross.

Number of lamps	Watts 1000	750	500	250	150	100	60	40	25
2	2000	1500	1000	500	300	200	120	80	50
3	3000	2250	1500	750	450	300	180	120	75
4	4000	3000	2000	1000	600	400	240	160	100
5	5000	3750	2500	1250	750	500	300	200	125
6	6000	4500	3000	1500	900	600	360	240	150
7	7000	5250	3500	1750	1050	700	420	280	175
8	8000	6000	4000	2000	1200	800	480	320	200
9	9000	6750	4500	2250	2700	900	540	360	225
10	10000	7500	5000	2500	1500	1000	600	400	250
15	15000	11250	7500	3750	2250	1500	900	600	375
20	20000	15000	10000	5000	3000	2000	1200	800	500
25	25000	18750	12500	6250	3750	2500	1500	1000	625
30	30000	22500	15000	7500	4500	3000	1800	1200	750
35	35000	26250	17500	8750	5250	3500	2100	1400	875
40	40000	30000	20000	10000	6000	4000	2400	1600	1000
45	45000	33750	22500	11250	6750	4500	2700	1800	1125
50	50000	37500	25000	12500	7500	5000	3000	2000	1250
55	55000	41250	27500	13750	8250	5500	3300	2200	1375
60	60000	45000	30000	15000	9000	6000	3600	2400	1500
65	65000	48750	32500	16250	9750	6500	3900	2600	1625
70	70000	52500	35000	17500	10500	7000	4200	2800	1750
75	75000	56250	37500	18750	11250	7500	4500	3000	1875
80	80000	60000	40000	20000	12000	8000	4800	3200	2000
85	85000	63750	42500	21250	12750	8500	5100	3400	2125
90	90000	67500	45000	22500	13500	9000	5400	3600	2025
100	100000	75000	50000	25000	15000	10000	6000	4000	2500
110	110000	82500	55000	27500	16500	11000	6600	4400	2750
120	120000	90000	60000	30000	18000	12000	7200	4800	3000
130	130000	92500	65000	32500	19500	13000	7800	5200	3250
140	140000	105000	70000	35000	21000	14000	8400	5600	3500
150	150000	112500	75000	37500	22500	15000	9000	6000	3750

TABLE CI

Table showing wattage capacity of different wires

	—110 Volts—		—220 Volts—		—440 Volts—	
	Rubber Ins.	Other Ins.	Rubber Ins.	Other Ins.	Rubber Ins.	Other Ins.
14	1650	2200	3300	4400	6600	8800
12	2200	2750	4400	5500	8800	11000
10	2750	3300	5500	6600	11000	13200
8	3850	5500	7700	11000	15400	22000
6	5500	7700	11000	15400	22000	30800
5	6050	8800	12100	17600	24200	35200
4	7700	9900	15400	19800	30800	39600
3	8800	11000	17600	22000	35200	44000
2	9900	13750	19800	27500	39600	55000
1	11000	16500	22000	33000	44000	66000
0	13750	22000	27500	44000	55000	88000
00	16500	24750	33000	49500	66000	99000
000	19250	30250	38500	60500	77000	121000
0000	24750	35750	49500	71500	99000	143000
200000	22000	33000	44000	66000	88000	132000
300000	30250	44000	60500	88000	121000	176000
400000	35750	55000	71500	110000	143000	220000
500000	44000	66000	88000	132000	176000	264000

If system is balanced use columns 220 volts for 3-wire 110-volt systems and column 440 volts for 3-wire 220 volt systems or for such voltages direct.

Tables for calculating amperage of motors with various efficiencies, power factors systems and voltages.

RULE FOR FINDING AMPERES

In top part of table select numbers found where lines pertaining to efficiency and power factors cross and find same number in middle table. In same line under proper system will be found the number of amperes required for 1 H. P. at 110 volts. In bottom table select divisor pertaining to higher voltages, divide amperes by this and multiply by number of H. P. The result will give the total number of amperes required. The efficiency of small motors is always much less than that of larger motors.

TABLE CII

Power Factors	Efficiency .95	.90	.87½	.85	.82½	.80	.75	.70	.65	.60	.55
.95	.90	.86	.83	.81	.78	.76	.71	.67	.62	.57	.53
.90	.86	.81	.79	.77	.74	.72	.68	.63	.59	.54	.50
.85	.81	.77	.74	.72	.70	.68	.64	.60	.55	.51	.47
.80	.76	.72	.70	.68	.66	.64	.60	.56	.52	.48	.44
.75	.71	.68	.66	.64	.62	.60	.56	.53	.49	.45	.41
.70	.67	.63	.61	.59	.58	.56	.53	.49	.46	.42	.39

Amperes for 1 H. P. at 110 Volts

	Direct current or s. phase	Two phase	Three phase		Direct current or s. phase	Two phase	Three phase
.39	17.4	12.5	10.0	.66	10.3	7.3	5.9
.41	16.5	11.9	9.6	.67	10.1	7.2	5.9
.42	16.1	11.6	9.3	.68	9.9	7.1	5.8
.44	15.4	11.1	8.9	.70	9.7	7.0	5.6
.45	15.1	10.8	8.7	.71	9.6	6.9	5.5
.46	14.7	10.5	8.6	.72	9.5	6.8	5.4
.47	14.4	10.3	8.4	.74	9.2	6.6	5.3
.48	14.1	10.2	8.2	.76	8.9	6.4	5.1
.49	13.8	9.9	8.0	.77	8.8	6.3	5.1
.50	13.6	9.7	7.8	.78	8.7	6.2	5.0
.51	13.3	9.5	7.6	.79	8.6	6.1	5.0
.52	13.0	9.4	7.5	.81	8.4	6.0	4.8
.53	12.8	9.2	7.4	.83	8.2	5.9	4.7
.54	12.6	9.0	7.3	.84	8.1	5.8	4.6
.55	12.4	8.8	7.1	.85	8.0	5.7	4.6
.56	12.1	8.7	7.0	.86	7.9	5.7	4.5
.57	11.9	8.5	6.8	.90	7.5	5.4	4.3
.58	11.7	8.4	6.7	.92	7.4	5.3	4.3
.59	11.5	8.3	6.6	.93	7.3	5.2	4.2
.60	11.3	8.1	6.5	.94	7.2	5.2	4.2
.61	11.1	8.0	6.4	.95	7.1	5.1	4.1
.62	10.9	7.8	6.3	.96	7.0	5.1	4.1
.63	10.7	7.7	6.2	.97	7.0	5.0	4.0
.64	10.6	7.6	6.1	.98	6.9	4.9	4.0

Voltages

	110	220	440	550	650	1100	2080	2200
Divisor	1	2	4	5	5.9	11	18.9	20

DIRECT CURRENT MOTORS

TABLE CIII

Direct Current Motors

Table Showing Maximum H. P. Allowed on Wires According to N. E. Code Rules and Carrying Capacities. Assumed Efficiency of Motors, .90.

Carrying Capacities			110 Volts				220 Volts				550 Volts				650 Volts			
			Mains		Branches		Mains		Branches		Mains		Branches		Mains		Branches	
R.I.	O.I.	B. & S.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.
15	20	14	2.0	2.7	1.6	2.1	4.0	5.4	3.2	4.2	10.0	13.5	8.0	10.5	11.8	15.9	9.4	12.4
20	25	12	2.7	3.3	2.1	2.7	5.4	6.6	4.2	5.4	13.5	16.5	10.5	13.5	15.9	19.5	12.4	15.9
25	30	10	3.3	4.0	2.7	3.2	6.6	8.0	5.4	6.4	16.5	20.0	13.5	16.0	19.5	23.6	15.7	18.9
35	50	8	4.7	6.7	3.7	5.4	9.4	13.4	7.4	10.8	23.5	33.5	18.5	27.0	27.8	39.5	21.8	31.8
50	70	6	6.6	9.3	5.3	7.7	13.2	18.6	10.6	15.4	33.0	46.5	26.5	38.5	38.9	54.9	31.3	45.4
55	80	5	7.3	10.7	5.8	8.5	14.6	21.4	11.6	17.0	36.5	53.5	29.0	42.5	43.1	63.1	34.2	50.1
70	90	4	9.3	12.0	7.4	9.6	18.6	24.0	14.8	19.2	46.5	60.0	37.0	48.0	54.9	70.8	43.7	56.6
80	100	3	10.7	13.3	8.5	10.6	21.4	26.6	17.0	21.2	53.5	66.5	42.5	53.0	63.1	78.5	50.1	62.5
90	125	2	12.0	16.7	9.6	13.3	24.0	33.4	19.2	26.6	60.0	83.5	48.0	66.5	70.8	98.5	56.7	78.5
100	150	1	13.3	20.0	10.6	16.0	26.6	40.0	21.2	32.0	66.5	100.	53.0	80.0	78.5	118.0	62.5	94.4
125	200	0	16.7	26.7	13.3	21.2	33.4	53.4	26.6	42.4	83.5	133.5	66.5	106.0	98.5	157.5	78.5	125.1
150	225	00	20.0	30.0	16.0	23.9	40.0	60.0	32.0	47.8	100.0	150.0	80.0	119.5	118.0	177.0	94.4	141.0
175	275	000	23.3	36.7	18.6	29.3	46.6	73.4	37.2	58.6	116.5	183.5	93.0	146.5	137.5	216.5	109.7	172.9
225	325	0000	30.0	43.3	24.0	34.6	60.0	86.6	48.0	69.2	150.0	216.5	120.0	173.0	177.0	255.5	141.6	204.1
200	300	200000	26.6	40.0	21.3	32.0	53.2	80.0	42.6	64.0	133.0	200.0	106.5	160.0	156.9	236.0	125.7	188.8

To find smallest wire permissible for a given motor load, find H. P. under proper voltage and insulation of wire; in same horizontal line under B. & S. will be found the gauge number of the wire to be used.

DIRECT CURRENT MOTORS

TABLE CIV

Direct Current Motors

Carrying Capacities		Cir. Mils.	110 Volts				220 Volts				550 Volts				650 Volts			
			Mains		Branches		Mains		Branches		Mains		Branches		Mains		Branches	
R.I.	O.I.		R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.
275	400	300000	36.6	53.3	29.2	42.5	73	106	58	85	183	266	146	212	216	314	172	251
325	500	400000	43.3	66.6	34.4	53.2	86	133	68	106	216	333	172	266	255	393	203	314
400	600	500000	53.3	80.0	42.5	63.8	106	160	85	128	266	400	212	319	314	472	251	376
450	680	600000	60.0	90.6	47.9	72.3	120	181	96	145	300	453	239	361	354	534	283	427
500	760	700000	66.6	102.3	53.2	80.8	133	202	106	162	333	506	266	404	393	598	314	477
550	840	800000	73.3	112.0	58.5	89.4	147	224	117	179	366	560	292	497	432	661	345	527
600	920	900000	80.0	122.6	63.8	97.9	160	245	128	196	400	613	319	489	472	723	376	528
650	1000	1000000	86.6	133.3	69.1	106.4	173	266	138	213	433	666	345	532	511	786	408	628
690	1080	1100000	92.0	144.0	73.4	115.0	184	288	147	230	460	720	367	575	543	850	433	678
730	1150	1200000	97.3	153.3	77.7	122.3	195	306	155	245	486	766	388	611	574	904	458	721
770	1220	1300000	102.6	162.6	81.9	129.7	205	325	164	259	513	813	409	648	605	959	483	765
810	1290	1400000	108.0	172.0	86.2	137.2	216	344	172	274	540	860	431	686	637	1015	509	809
850	1360	1500000	113.3	181.3	90.4	145.0	226	362	181	290	566	906	452	725	668	1070	533	855
890	1430	1600000	118.6	190.6	94.7	152.1	237	381	189	304	593	953	473	760	700	1124	559	897
930	1490	1700000	124.0	199.0	99.0	158.5	248	398	198	317	620	995	495	792	732	1174	584	935
970	1550	1800000	129.3	206.6	103.2	165.0	258	413	206	330	646	1033	516	825	763	1219	609	973
1010	1610	1900000	134.6	214.6	107.4	171.2	269	429	215	342	673	1073	537	856	794	1266	634	1010
1050	1670	2000000	140.0	222.6	111.7	177.6	280	445	223	355	700	1113	558	888	826	1313	659	1048

To find the smallest wire permissible for a given motor load, find H. P. under proper voltage and insulation of wire; in same horizontal line under B. & S. will be found the gauge number of the wire to be used.

SINGLE PHASE MOTORS

TABLE CV

Single Phase Motors

Table Showing Maximum H. P. Allowed on Wires, According to N. E. Code Rules, and Carrying Capacities. Assumed Efficiency, .90; Power Factor, .85.

Carrying Capacities			110 Volts				220 Volts				440 Volts				550 Volts			
			Mains		Branches		Mains		Branches		Mains		Branches		Mains		Branches	
R.I.	O.I.	B. & S.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.
15	20	14	1.7	2.2	1.37	1.8	3.4	4.4	2.7	3.6	6.8	8.8	5.4	7.2	8.5	11.0	6.8	9.0
20	25	12	2.2	2.8	1.8	2.3	4.4	5.6	3.6	4.6	8.8	11.2	7.2	9.2	11.0	14.0	9.0	11.5
25	30	10	2.8	3.4	2.3	2.7	5.6	6.8	4.6	5.4	11.2	13.6	9.2	10.8	14.0	17.0	11.5	13.5
35	50	8	3.9	5.6	3.2	4.6	7.9	11.2	6.4	9.2	15.8	22.4	12.8	18.4	19.8	28.0	16.0	23.0
50	70	6	5.6	7.9	4.5	6.4	11.3	15.8	9.0	12.8	22.6	31.6	18.0	25.6	28.2	39.5	22.5	32.0
55	80	5	6.2	9.0	5.0	7.3	12.4	18.0	10.0	14.6	24.8	36.0	20.0	29.2	31.0	45.0	25.0	36.5
70	90	4	7.9	10.1	6.4	8.2	15.8	20.2	12.8	16.4	31.6	40.4	25.6	32.8	39.5	50.5	32.0	41.0
80	100	3	9.0	11.3	7.3	9.1	18.0	22.6	14.6	18.2	36.0	45.2	29.2	36.4	45.0	56.5	36.5	45.5
90	125	2	10.1	14.1	8.2	11.4	20.2	28.2	16.4	22.8	40.4	56.4	32.8	45.6	50.5	70.5	41.0	57.0
100	150	1	11.3	17.0	9.1	13.7	22.6	34.0	18.2	27.4	45.2	68.0	36.4	54.8	56.5	85.0	45.5	68.5
125	200	0	14.1	22.5	11.4	18.2	28.2	45.0	22.8	36.4	56.4	90.0	45.6	72.8	70.5	112.5	57.0	91.0
150	225	00	16.9	25.4	13.6	20.5	33.8	50.8	27.2	41.0	67.6	101.6	54.4	82.0	84.5	127.0	68.0	102.5
175	275	000	19.7	31.0	15.9	25.0	39.4	62.0	31.8	50.0	78.8	124.0	63.6	100.0	98.5	155.0	79.5	125.0
225	325	0000	25.4	36.6	20.4	29.5	50.8	73.2	40.8	59.0	101.6	146.4	81.6	118.0	127.0	183.0	102.0	147.5
200	300	20000	22.5	33.8	18.2	27.3	45.0	67.6	36.4	54.6	90.0	133.2	72.8	109.2	112.5	169.0	91.0	136.5
275	400	300000	31.0	45.1	25.0	36.3	62.0	90.2	50.0	72.6	124.0	180.4	100.0	145.2	155.0	225.5	125.0	181.5
325	500	400000	36.6	56.4	29.5	45.4	73.2	112.8	59.0	90.8	146.4	225.6	118.0	181.6	183.0	282.0	147.5	227.0
400	600	500000	45.1	67.7	36.4	54.5	90.2	134.4	72.8	109.0	180.4	270.8	145.6	218.0	225.5	338.5	182.0	272.5

To find smallest wire permissible for a given motor load, find H. P. under proper voltage and insulation of wire; in same horizontal line under B. & S. will be found the gauge number of the wire to be used.

TWO PHASE MOTORS

TABLE CVI

Two Phase Motors

Table Showing Maximum H. P. Allowed on Wires, According to N. E. Code Rules, and Carrying Capacities. Assumed Efficiency, .90; Power Factor, .85.

Carrying Capacities			110 Volts				220 Volts				440 Volts				550 Volts			
			Mains		Branches		Mains		Branches		Mains		Branches		Mains		Branches	
R.I.	O.I.	B. & S.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.
15	20	14	3.4	4.4	2.7	3.6	6.8	8.8	5.4	7.2	13.6	17.6	10.8	14.4	17.0	22.0	13.6	18.0
20	25	12	4.4	5.6	3.6	4.6	8.8	11.2	7.2	9.2	17.6	22.4	14.4	18.4	22.0	28.0	18.0	23.0
25	30	10	5.6	6.8	4.6	5.4	11.2	13.6	9.2	10.8	22.4	27.2	18.4	21.6	28.0	34.0	23.0	27.0
35	50	8	7.8	11.2	6.4	9.2	15.8	22.4	12.8	18.4	31.6	44.8	25.6	36.8	39.6	56.0	32.0	46.0
50	70	6	11.2	15.8	9.0	12.8	22.6	31.6	18.0	25.6	45.2	63.2	36.0	51.2	56.4	79.0	45.0	64.0
55	30	5	12.4	18.0	10.0	14.6	24.8	36.0	20.0	29.2	49.6	72.0	40.0	58.4	62.0	90.0	50.0	73.0
70	90	4	15.8	20.2	12.8	16.4	31.6	40.4	25.6	32.8	63.2	80.8	51.2	65.6	79.0	101.0	64.0	82.0
80	100	3	18.0	22.6	14.6	18.2	36.0	45.2	29.2	36.4	72.0	90.4	58.4	72.8	90.0	113.0	73.0	91.0
90	125	2	20.2	28.2	16.4	22.8	40.4	56.4	32.8	45.6	80.8	112.8	65.6	91.2	101.0	141.0	82.0	114.0
100	150	1	22.6	34.0	18.2	27.4	45.2	68.0	36.4	54.8	90.4	136.0	72.8	109.6	113.0	170.0	91.0	137.0
125	200	0	28.2	45.0	22.8	36.4	56.4	90.0	45.6	72.8	112.8	180.0	91.2	145.6	141.0	225.0	114.0	182.0
150	225	00	33.8	50.8	27.2	41.0	67.6	101.6	54.4	82.0	135.2	203.2	108.8	164.0	169.0	254.0	136.0	205.0
175	275	000	39.4	62.0	31.8	50.0	78.8	124.0	63.6	100.0	157.6	248.0	127.2	200.0	197.0	310.	159.0	250.0
225	325	0000	50.8	73.2	40.8	59.0	101.6	146.4	81.6	118.0	203.2	292.8	163.2	236.0	254.0	366.	204.0	295.0
200	300	200000	45.0	67.6	36.4	54.6	90.0	135.2	72.8	109.2	180.0	266.4	145.6	218.4	225.0	338.	182.0	273.0
275	400	300000	62.0	90.2	50.0	72.6	124.0	180.4	100.0	145.2	248.0	360.8	200.0	290.4	310.0	451.	250.0	363.0
325	500	400000	73.2	112.8	59.0	90.8	146.4	225.6	118.0	181.6	292.8	451.2	236.0	363.2	366.0	564.0	295.0	454.0
400	600	500000	90.2	135.4	72.8	109.0	180.4	268.8	145.6	218.0	360.8	541.6	291.2	436.0	451.0	677.0	364.0	545.0

To find smallest wire permissible for a given motor load, find H. P. under proper voltage and insulation of wire; in same horizontal line under B. & S. will be found the gauge number of the wire to be used

THREE PHASE MOTORS

TABLE CVII

Three Phase Motors

Table Showing Maximum H. P. Allowed on Wires, According to N. E. Code Rules, and Carrying Capacities. Assumed Efficiency, .90; Power Factor, .85.

Carrying Capacities			110 Volts				220 Volts				440 Volts				550 Volts			
			Mains		Branches		Mains		Branches		Mains		Branches		Mains		Branches	
R.I.	O.I.	B. & S.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.
15	20	14	2.9	3.9	2.34	3.1	5.8	7.8	4.6	6.2	11.6	15.6	9.2	12.4	14.5	19.5	11.5	15.5
20	25	12	3.9	4.9	3.1	3.9	7.8	9.8	6.2	7.8	15.6	19.6	12.4	15.6	19.5	24.5	15.5	19.5
25	30	10	4.9	5.9	3.9	4.7	9.8	11.8	7.8	9.4	19.6	23.6	15.6	18.8	24.5	29.5	19.5	23.5
35	50	8	6.9	9.8	5.5	7.8	13.8	19.6	11.0	15.6	27.6	39.2	22.0	31.2	34.5	49.0	27.5	39.0
50	70	6	9.8	13.7	7.8	10.9	19.6	27.4	15.6	21.8	39.2	54.8	31.2	43.6	49.0	68.5	39.0	54.5
55	80	5	10.8	15.7	8.6	12.5	21.6	31.4	17.2	25.0	43.2	62.8	34.4	50.0	54.0	78.5	43.0	62.5
70	90	4	13.7	17.6	10.9	14.1	27.4	35.2	21.8	28.2	54.8	70.4	43.6	56.4	68.5	88.0	54.5	70.5
80	100	3	15.7	19.6	12.5	15.6	31.4	39.2	25.0	31.2	62.8	78.4	50.0	62.4	78.5	98.0	62.5	78.0
90	125	2	17.6	24.5	14.1	19.5	35.2	49.0	28.2	39.0	70.4	98.0	56.4	78.0	88.0	122.5	70.5	97.5
100	150	1	19.6	29.4	15.6	23.4	39.2	58.8	31.2	46.8	78.4	117.6	62.4	93.6	98.0	147.0	78.0	117.0
125	200	0	24.5	39.2	19.5	31.2	49.0	78.4	39.0	62.4	98.0	156.8	78.0	124.8	122.5	196.0	97.5	156.0
150	225	00	29.4	44.1	23.4	35.1	58.8	88.2	46.8	70.2	117.6	176.4	93.6	140.4	147.0	220.5	117.0	176.0
175	275	000	34.3	53.9	27.3	42.9	68.6	107.8	54.6	85.8	137.2	215.6	109.2	171.6	171.5	269.5	136.5	214.5
225	325	0000	44.1	63.7	35.1	50.8	88.2	127.4	70.2	101.6	176.4	254.8	140.4	203.2	220.5	318.5	175.5	254.0
200	300	200000	39.2	58.8	31.2	46.9	78.4	117.6	62.4	93.8	156.8	235.2	124.8	187.6	196.0	294.0	156.0	234.5

To find smallest wire permissible for a given motor load, find H. P. under proper voltage and insulation of wire; in same horizontal line under B. & S. will be found the gauge number of the wire to be used.

THREE PHASE MOTORS

TABLE CVIII

Three Phase Motors

Carrying Capacities		Cir. Mils.	110 Volts				220 Volts				440 Volts				550 Volts			
			Mains		Branches		Mains		Branches		Mains		Branches		Mains		Branches	
R.I	O.I.		R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.	R.I.	O.I.
275	400	300000	54	78	43	62	108	156	86	125	216	312	172	248	270	390	215	310
325	500	400000	64	98	51	78	128	196	102	156	256	392	204	312	320	490	255	390
400	600	500000	78	117	62	94	156	234	124	188	312	468	248	376	390	585	310	470
450	680	600000	88	133	70	106	176	266	140	212	352	532	280	424	440	665	350	530
500	760	700000	98	149	78	119	196	298	156	238	392	596	312	476	490	745	390	595
550	840	800000	108	164	86	131	216	328	172	262	432	656	344	524	540	820	430	655
600	920	900000	117	180	94	143	234	360	188	286	468	720	376	572	585	900	470	715
650	1000	1000000	127	196	102	156	254	392	204	312	508	784	408	624	635	980	510	780
690	1080	1100000	135	211	108	169	270	422	216	338	540	844	432	676	675	1055	540	845
730	1150	1200000	143	225	114	179	286	450	228	358	572	900	456	716	715	1125	570	895

To find the smallest wire permissible for a given motor load, find H. P. under proper voltage and insulation of wire; in same horizontal line under B. & S. will be found the gauge number of the wire to be used.

Tables for Calculating Drop in Voltage.—The drop in voltage in a direct current circuit is always equal to IR, while in an alternating current circuit it is equal to IZ. These formulae are, however, not well suited for use when the problem is to find the proper wire to be used where the loss is determined upon.

That portion of the following tables devoted to direct currents consists simply of one column of figures in which are given the conductances of the various wires. That part of the tables used for alternating current circuits gives the admittances of the various wires under different circumstances. The losses in voltage which form the basis of the following tables have been calculated from the formula:

$$\sqrt{[(E \times p.f.) + (IR)]^2 + [(E \times r.f.) + (IX)]^2} = E^1$$

where E stands for voltage to be delivered at end of line; $p.f.$ for power factor of load; I for current in amperes; R for ohmic resistance of line; $r.f.$ for reactive factor; X for reactive volts in line, and E^1 for the e.m.f. necessary at the starting point to deliver E at the end of line. The ohmic resistance and the reactive volts can be taken from Tables CIX and CX and the power factor (cosine of angle of lag) and reactive factor (sine of angle of lag) from Table CXI. To obtain the loss in volts it is necessary to subtract E from E^1. Referring to Figure 34, which illustrates the common method of figuring drop in voltage for alternating current circuits, the losses for which the tables are calculated are equal to the difference between the lines A and B.

Having thus briefly outlined how the line losses, used as the basis of the following tables have been derived, we may now proceed to explain the tables and the method of their use.

Since, according to a transposition of Ohms law, $\frac{E}{I} = R$ it follows that $\frac{I}{E} = \frac{1}{R}$. In other words $\frac{1}{R}$ or $\frac{1}{Z}$ give us the conductance or admittance which in connection with the current I will consume the voltage E. The numerical value of conductance or admittance in any line equals the number of amperes which can be transmitted over that line at a loss of one volt. This conductance for direct currents and admittance for alternating currents has been tabulated in the following pages. Hence, if we divide the current to be trans-

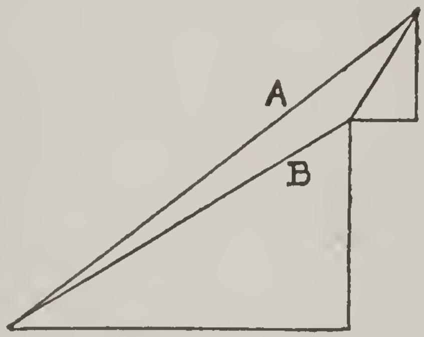


Figure 34.

mitted by the volts we wish to lose we shall obtain the value of the conductance or admittance which is necessary to cause this loss. The basis of the table is a line of 100 feet in length, which represents 200 feet of wire of a two-wire line. In order to find a wire which shall give us any desired loss, we need then merely to find what that loss is to be per 100 feet of line, and divide the amperes to be transmitted by this loss; then trace down the column describing the conditions (direct current or separation of wires) until we come to a number which about equals the one previously found. In connection with three-phase systems, if great accuracy is required, it will be necessary to divide the volts to be lost by 0.86 before proceeding with the rest.

In order to facilitate the calculations, the tables, CXII to CXIII, have been added. Table CXII gives the average value of amperes per H. P. with various voltages, and table CXIII shows the value in actual volts per hundred feet run of 1 per cent loss with the distances and voltages given. If the loss to be allowed over any distance and with any of the voltages given is stated in per cent, we need merely to multiply the number found where distance and voltage cross by the number of per cent to find the number of volts to be lost per 100 feet.

Example: We have 50 H.P., three-phase, 60 cycles, at 1000 volts, to transmit a distance of 2200 feet, with 24-inch separation, at a loss of 5 per cent. What size of wire must be used? Fifty H.P. three phase at 1000 volts equals 35 amperes. (See Table CXII.) For a voltage of 1000 and a distance of 2200 feet the number with which we must divide our current for one per cent is .451. (See Table CXIII.)

This multiplied by the percentage of loss, 5 = 2.255, and this, in turn, divided by 0.86, gives us 2.62, with which we divide our amperes, 35, and obtain 13.3 as the admittance required. Tracing downward in table CXIV under the proper separation, 24 inches, we find the number 14.2 as the nearest, and this indicates a No. 5 wire. The same plan is used for direct current, and the conductances are given in column D. C. If larger wires are indicated, the conductances of the larger wire are in proportion to the circular mils for direct current.

TABLE CIX

Table Showing Reactance and Resistance Volts, 1 Ampere, 100 Feet Run (200 Ft. Wire).

60 Cycles

Copper Wire B. & S.	Resistance Volts	Reactance Volts — Separation of Wires in Inches ½	3	6	12	24	36	48	60	72	Resistance Volts Aluminum Wire
14	0.511	.0138	0.0220	0.0252	0.0282	0.0315	0.0334	0.0347	0.0358	0.0366	0.814
12	0.323	.0127	0.0209	0.0241	0.0273	0.0305	0.0323	0.0336	0.0347	0.0355	0.512
10	0.2036	.0116	0.0198	0.0230	0.0262	0.0243	0.0313	0.0326	0.0337	0.0345	0.322
8	0.1308	.0106	0.0188	0.0220	0.0251	0.0283	0.0302	0.0315	0.0325	0.0334	0.202
6	0.082	.0095	0.0177	0.0209	0.0241	0.0273	0.0291	0.0304	0.0315	0.0323	0.1274
5	0.0652	.0090	0.0171	0.0204	0.0236	0.0267	0.0285	0.0298	0.0308	0.0316	0.1010
4	0.0518	.0085	0.0167	0.0199	0.0231	0.0262	0.0280	0.0293	0.0303	0.0312	0.0801
3	0.041	.0079	0.0162	0.0194	0.0226	0.0257	0.0275	0.0288	0.0298	0.0307	0.0635
2	0.0324	.0074	0.0156	0.0188	0.0220	0.0251	0.0269	0.0283	0.0293	0.0301	0.0504
1	0.0258	.0068	0.0151	0.0182	0.0214	0.0246	0.0264	0.0278	0.0288	0.0296	0.0399
0	0.0204	.0063	0.0146	0.0177	0.0209	0.0240	0.0259	0.0272	0.0282	0.0291	0.0317
00	0.0162	.0057	0.0140	0.0172	0.0204	0.0235	0.0254	0.0267	0.0277	0.0285	0.0251
000	0.0128	.0052	0.0135	0.0167	0.0199	0.0230	0.0248	0.0262	0.0272	0.0280	0.0199
0000	0.0102	.0046	0.0129	0.0161	0.0193	0.0225	0.0243	0.0257	0.0267	0.0275	0.0158
250000	0.0086		0.0125	0.0157	0.0189	0.0221	0.0239	0.0253	0.0263	0.0271	0.0138
300000	0.0072		0.0121	0.0153	0.0185	0.0217	0.0235	0.0249	0.0259	0.0267	0.0115
350000	0.00616		0.0118	0.0149	0.0181	0.0213	0.0232	0.0245	0.0255	0.0264	0.0098
400000	0.00540		0.0113	0.0144	0.0176	0.0208	0.0228	0.0241	0.0251	0.0260	0.0086
500000	0.00432		0.0109	0.0141	0.0173	0.0205	0.0224	0.0237	0.0247	0.0255	0.0069
600000	0.00360		0.0106	0.0137	0.0169	0.0201	0.0219	0.0233	0.0244	0.0251	0.0057
700000	0.00308		0.0103	0.0134	0.0166	0.0198	0.0215	0.0230	0.0240	0.0247	0.0049
750000	0.00288		0.0100	0.0132	0.0164	0.0196	0.0214	0.0228	0.0238	0.0246	0.0046
800000	0.00270		0.0098	0.0130	0.0162	0.0193	0.0212	0.0225	0.0236	0.0244	0.0043
900000	0.00240		0.0096	0.0127	0.0159	0.0190	0.0209	0.0222	0.0233	0.0241	0.0038
1000000	0.00216		0.0094	0.0126	0.0157	0.0189	0.0208	0.0221	0.0231	0.0239	0.0035

TABLE CX

Table Showing Reactance and Resistance Volts, 1 Ampere, 100 Feet Run (200 Ft. Wire).

25 Cycles

Copper Wire		Reactance Volts									Resistance Volts
	Resistance	Separation in Inches									Aluminum
B. & S.	Volts	½	3	6	12	24	36	48	60	72	Wire
14	0.511	0.0057	0.0091	0.0105	0.0117	0.0131	0.0139	0.0145	0.0149	0.0152	0.814
12	0.323	0.0053	0.0087	0.0100	0.0114	0.0127	0.0135	0.0140	0.0145	0.0148	0.512
10	0.2036	0.0048	0.0083	0.0097	0.0110	0.0122	0.0130	0.0136	0.0140	0.0144	0.322
8	0.1308	0.0044	0.0078	0.0092	0.0105	0.0118	0.0126	0.0131	0.0135	0.0139	0.202
6	0.082	0.0039	0.0074	0.0087	0.0100	0.0114	0.0121	0.0127	0.0131	0.0135	0.1274
5	0.0652	0.0037	0.0071	0.0085	0.0098	0.0111	0.0119	0.0124	0.0129	0.0132	0.1010
4	0.0518	0.0036	0.0069	0.0083	0.0096	0.0109	0.0117	0.0122	0.0126	0.0130	0.0801
3	0.041	0.0033	0.0067	0.0081	0.0094	0.0107	0.0115	0.0120	0.0124	0.0128	0.0635
2	0.0324	0.0031	0.0065	0.0078	0.0092	0.0105	0.0112	0.0118	0.0122	0.0125	0.0504
1	0.0258	0.0027	0.0063	0.0076	0.0089	0.0103	0.0110	0.0116	0.0120	0.0123	0.0399
0	0.0204	0.0026	0.0061	0.0074	0.0087	0.0100	0.0108	0.0113	0.0118	0.0121	0.0317
00	0.0162	0.0024	0.0059	0.0072	0.0085	0.0098	0.0106	0.0111	0.0115	0.0119	0.0251
000	0.0128	0.0022	0.0056	0.0070	0.0083	0.0096	0.0103	0.0109	0.0113	0.0117	0.0199
0000	0.0102	0.0019	0.0054	0.0067	0.0080	0.0094	0.0101	0.0107	0.0117	0.0115	0.0158
250000	0.0086		0.0052	0.0065	0.0078	0.0092	0.0099	0.0106	0.0109	0.0113	0.0138
300000	0.0072		0.0050	0.0064	0.0077	0.0090	0.0098	0.0104	0.0107	0.0111	0.0115
350000	0.00616		0.0049	0.0062	0.0075	0.0088	0.0097	0.0102	0.0106	0.0110	0.0098
400000	0.00540		0.0048	0.0060	0.0073	0.0087	0.0095	0.0100	0.0105	0.0109	0.0086
500000	0.00432		0.0046	0.0059	0.0072	0.0086	0.0093	0.0099	0.0103	0.0106	0.0069
600000	0.00360		0.0044	0.0057	0.0070	0.0084	0.0091	0.0098	0.0102	0.0105	0.0057
700000	0.00308		0.0043	0.0056	0.0069	0.0083	0.0090	0.0096	0.0100	0.0103	0.0049
750000	0.00288		0.0042	0.0055	0.0068	0.0082	0.0089	0.0095	0.0099	0.0102	0.0046
800000	0.00270		0.0041	0.0054	0.0067	0.0080	0.0088	0.0094	0.0098	0.0101	0.0043
900000	0.00240		0.0040	0.0053	0.0066	0.0079	0.0087	0.0093	0.0097	0.0100	0.0038
1000000	0.00216		0.0039	0.0052	0.0065	0.0078	0.0086	0.0092	0.0096	0.0099	0.0035

TABLE CXI

Power and Reactive Factors for Different Angles of Lag or Lead

Degres Lag or Lead	Power Factors Cosine ϕ	Reactive Factors Sine ϕ	Degres Lag or Lead	Power Factors Cosine ϕ	Reactive Factors Sine ϕ	Degres Lag or Lead	Power Factors Cosine ϕ	Reactive Factors Sine ϕ
1	.999	.017	31	.857	.515	61	.485	.875
2	.999	.035	32	.848	.530	62	.469	.883
3	.998	.052	33	.839	.545	63	.454	.891
4	.997	.070	34	.829	.559	64	.438	.899
5	.996	.087	35	.819	.574	65	.423	.906
6	.994	.105	36	.809	.588	66	.407	.914
7	.992	.122	37	.798	.602	67	.391	.921
8	.990	.139	38	.788	.616	68	.375	.927
9	.988	.156	39	.777	.629	69	.358	.934
10	.985	.174	40	.766	.643	70	.342	.940
11	.982	.191	41	.755	.656	71	.326	.946
12	.978	.208	42	.743	.669	72	.309	.951
13	.974	.225	43	.731	.682	73	.292	.956
14	.970	.242	44	.719	.695	74	.276	.961
15	.966	.259	45	.707	.707	75	.259	.966
16	.961	.276	46	.695	.719	76	.242	.970
17	.956	.292	47	.682	.731	77	.225	.974
18	.951	.309	48	.669	.743	78	.208	.978
19	.946	.326	49	.656	.755	79	.191	.982
20	.940	.342	50	.643	.767	80	.174	.985
21	.934	.358	51	.629	.777	81	.156	.988
22	.927	.375	52	.616	.788	82	.139	.990
23	.920	.391	53	.602	.799	83	.122	.992
24	.914	.407	54	.588	.809	84	.105	.994
25	.906	.423	55	.574	.819	85	.087	.996
26	.899	.438	56	.560	.829	86	.070	.997
27	.891	.454	57	.545	.839	87	.052	.998
28	.883	.470	58	.530	.848	88	.035	.999
29	.875	.485	59	.515	.857	89	.017	.999
30	.866	.500	60	.500	.866			

TABLE CXII

Table Showing Average Amperage Per H. P. or K. W. with Various Systems and Voltages of Transmission

Volts	Direct Current H.P.	Direct Current K.W.	Single Phase H.P.	Single Phase K.W.	Two Phase 4 Wire H.P.	Two Phase 4 Wire K.W.	Two Phase 3 Wire H.P.	Two Phase 3 Wire K.W.	Three Phase H.P.	Three Phase K.W.
110	8	10.7	11.0	14.7	5.5	7.4	7.7	10.3	6.4	8.5
220	4	5.4	5.5	7.4	2.8	3.7	3.8	5.2	3.2	4.2
440	2	2.7	2.8	3.7	1.4	1.9	1.9	2.6	1.6	2.1
650	1.3	1.8	1.8	2.5	1.0	1.3	1.3	1.7	1.1	1.4
1000	0.9	1.2	1.2	1.6	0.6	0.8	0.9	1.2	0.7	0.9

TABLE CXIII

Table Showing Divisors of Current for Use in Connection With Tables

Distance in Feet

Volts	100	200	300	400	500	600	700	800	900	1000	1100	1200	1320
110	1.1	.55	.367	.275	.220	.183	.157	.138	.122	.110	.100	.092	.083
220	2.2	1.10	.734	.550	.440	.366	.314	.276	.244	.220	.200	.184	.166
440	4.4	2.20	1.47	1.100	.880	.732	.628	.552	.488	.440	.400	.368	.332
650	6.5	3.25	2.17	1.63	1.30	1.08	.938	.813	.722	.650	.591	.542	.492
1000	10.0	5.00	3.34	2.50	2.00	1.67	1.43	1.25	1.11	1.000	.910	.833	.758

Distance in Feet

Volts	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500	2640
110	.079	.073	.069	.065	.061	.058	.055	.053	.050	.047	.046	.044	.041
220	.157	.146	.138	.130	.122	.116	.110	.106	.100	.094	.092	.088	.082
440	.314	.292	.276	.260	.244	.232	.220	.212	.200	.188	.184	.176	.164
650	.464	.433	.406	.382	.361	.342	.325	.309	.295	.283	.271	.260	.246
1000	.714	.667	.625	.588	.556	.527	.500	.476	.451	.435	.417	.400	.379

TABLE CXIV

The table below is designed to assist in selecting the proper wire for any desirable loss in connection with direct current and alternating current at 60 cycles.

Rule: Determine number of amperes to be transmitted and divide by number of volts to be lost per 100 feet of line (200 feet wire). Next trace down column under proper separation until a number equal to this or larger is found. In the same horizontal line and at the left under B. & S. will be found the gauge number of the wire to be used.

For three-phase systems, if great accuracy is required, divide volts to be lost by 0.86 before proceeding with the rest. Select no wire unless its carrying capacity is equal to the amperage required.

Copper Wire Carrying Capacities			Direct Current and 60 Cycle Alternating Power Factor 85%									
				Separation in Inches								
R. I.	O. I.	B. & S.	D. C.	½	3	6	12	24	36	48	60	72
15	20	14	1.95	1.96	1.95	1.98	1.98	1.98	1.98	1.98	1.98	1.98
20	25	12	3.09	3.10	3.15	3.14	3.13	3.13	3.12	3.12	3.11	3.11
25	30	10	4.91	4.99	4.98	4.96	4.94	4.93	4.92	4.91	4.90	4.89
35	50	8	7.64	7.44	7.37	7.32	7.28	7.24	7.22	7.20	7.19	7.17
50	70	6	12.2	12.3	12.00	11.9	11.8	11.6	11.5	11.5	11.4	11.4
55	80	5	15.3	15.5	15.0	14.8	14.5	14.2	14.1	14.0	13.9	13.8
70	90	4	19.3	19.3	18.4	18.1	17.6	17.2	16.9	16.7	16.6	16.5
80	100	3	24.4	24.3	22.8	22.2	21.4	20.7	20.2	19.9	19.7	19.5
90	125	2	30.9	30.6	27.9	26.8	25.6	24.4	23.9	23.6	22.2	22.7
100	150	1	38.7	38.0	33.4	31.7	29.8	28.1	27.2	26.7	26.0	25.7
125	200	0	49.0	47.1	39.9	37.1	34.4	32.1	30.6	29.8	29.0	28.5
150	225	00	61.7	58.6	46.9	42.4	38.9	35.6	33.8	32.7	31.8	31.2
175	275	000	78.1	72.6	54.3	48.2	42.9	39.1	36.7	35.1	34.2	33.3
225	325	0000	98.0	96.9	61.6	53.4	46.8	41.6	39.0	37.2	36.0	35.0
240	350	250000	116.3	....	67.0	57.1	49.5	44.2	43.0	38.6	37.2	36.4
275	400	300000	138.9	....	72.9	60.9	51.9	45.1	42.0	39.9	38.4	37.3
300	450	350000	162.3	....	77.3	64.1	54.1	46.6	43.1	40.9	39.4	38.1
325	500	400000	185.2	....	82.5	67.4	56.3	48.2	44.2	41.6	40.2	38.9
400	600	500000	231.5	....	88.3	70.3	58.1	49.4	45.3	42.8	41.1	40.0

TABLE CXV

The table below is designed to assist in selecting the proper wire for any desirable loss in connection with direct current and alternating current at 60 cycles.

Rule: Determine number of amperes to be transmitted and divide by number of volts to be lost per 100 feet of line (200 feet wire). Next trace down column under proper separation until a number equal to this or larger is found. In the same horizontal line and at the left under B. & S. will be found the gauge number of the wire to be used.

For three-phase systems, if great accuracy is required, divide volts to be lost by 0.86 before proceeding with the rest. Select no wire unless its carrying capacity is equal to the amperage required.

Copper Wire Carrying Capacities			Direct Current and 25 Cycle Alternating Power Factor 85%										
				Separation in Inches									
R. I.	O. I.	B. & S.	D. C.	½	3	6	12	24	36	48	60	72
15	20	14	1.95	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98
20	25	12	3.09	3.31	3.31	3.31	3.31	3.31	3.31	3.30	3.30	3.30
25	30	10	4.91	5.03	5.02	5.01	5.01	5.01	5.00	5.00	5.00	4.99
35	50	8	7.64	7.83	7.81	7.79	7.78	7.76	7.74	7.73	7.72	7.71
50	70	6	12.2	12.5	12.4	12.3	12.3	12.3	12.2	12.2	12.2	12.2
55	80	5	15.3	15.7	15.5	15.4	15.4	15.3	15.3	15.3	15.2	15.2
70	90	4	19.3	19.7	19.5	19.3	19.2	19.1	19.0	18.9	18.8	18.8
80	100	3	24.3	24.5	24.3	24.1	23.8	23.7	23.6	23.5	23.4	23.4
90	125	2	30.9	31.5	30.8	30.4	30.0	29.5	29.3	29.0	29.1	29.1
100	150	1	38.7	39.7	38.1	37.6	36.9	36.1	35.7	35.4	35.2	35.1
125	200	0	49.0	49.8	47.5	46.3	45.1	44.1	43.2	42.9	42.4	42.2
150	225	00	61.7	62.7	58.1	56.6	54.7	53.0	51.7	50.8	50.4	50.0
175	275	000	78.1	78.8	71.7	68.6	65.5	62.7	60.6	59.5	58.9	58.1
225	325	0000	98.0	98.2	86.9	82.1	84.2	72.3	70.1	68.2	66.9	65.6
240	350	250000	116.3	....	104.3	95.8	89.8	82.5	79.5	76.2	74.7	73.1
275	400	300000	138.9	....	114.1	104.5	95.8	87.8	83.6	80.4	79.2	77.2
300	450	350000	162.3	....	127.1	114.9	104.5	94.9	89.0	85.9	83.8	81.5
325	500	400000	185.2	....	138.8	125.5	112.3	100.0	94.3	90.6	87.4	84.9
400	600	500000	231.5	....	159.5	130.9	122.4	107.9	101.7	96.4	93.4	91.1

TABLE CXVI

The table below is designed to assist in selecting the proper wire for any desirable loss in connection with direct current and alternating current at 60 cycles.

Rule: Determine number of amperes to be transmitted and divide by number of volts to be lost per 100 feet of line (200 feet wire). Next trace down column under proper separation until a number equal to this or larger is found. In the same horizontal line and at the left under B. & S. will be found the gauge number of the wire to be used.

For three-phase systems, if great accuracy is required, divide volts to be lost by 0.86 before proceeding with the rest. Select no wire unless its carrying capacity is equal to the amperage required.

Aluminum Wire Carrying Capacities			Direct Current and 60 Cycle Alternating. Power Factor 0.85 Separation in Inches									
R. I.	O. I.	B. & S.	D. C.	½	3	6	12	24	36	48	60	72
12	17	14	1.23	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
17	21	12	1.95	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93
21	25	10	3.11	3.14	3.13	3.13	3.13	3.12	3.12	3.12	3.12	3.12
29	42	8	4.95	5.00	4.99	4.98	4.97	4.96	4.95	4.94	4.93	4.93
42	59	6	7.85	7.95	7.72	7.82	7.78	7.73	7.70	7.68	7.66	7.64
46	67	5	9.90	10.2	9.87	9.78	9.71	9.63	9.56	9.53	9.50	9.47
59	76	4	12.40	12.6	12.3	12.2	12.1	11.9	11.8	11.7	11.6	11.5
67	84	3	15.70	15.8	15.4	15.1	14.8	14.6	14.4	14.3	14.3	14.2
76	105	2	19.80	19.9	19.0	18.6	18.1	17.7	17.4	17.3	17.2	17.1
84	126	1	25.10	25.1	23.5	22.9	22.1	21.4	20.9	20.5	20.3	20.1
105	168	0	31.50	31.3	28.7	27.6	26.4	25.1	24.4	24.0	23.5	23.3
126	189	00	39.80	39.5	34.8	32.7	30.8	29.2	28.1	27.4	26.9	26.5
147	231	000	50.20	49.1	41.7	38.6	35.6	33.1	31.7	30.6	30.0	29.4
189	273	0000	63.30	61.1	49.0	44.4	40.4	36.7	34.9	33.6	32.6	31.9
202	294	250000	72.40	....	53.8	48.2	43.1	38.9	36.5	35.3	34.2	33.4
231	336	300000	86.90	....	60.3	52.9	46.5	41.4	38.9	37.2	36.0	35.1
252	378	350000	102.00	....	65.8	56.8	49.5	43.5	40.5	38.7	37.4	36.3
273	420	400000	116.30	....	71.1	60.6	52.1	45.4	41.9	40.0	38.6	37.4
336	504	500000	144.90	....	78.9	65.0	54.9	47.4	43.9	41.5	40.0	38.8

TABLE CXVII

The table below is designed to assist in selecting the proper wire for any desirable loss in connection with direct current and alternating current at 60 cycles.

Rule: Determine number of amperes to be transmitted and divide by number of volts to be lost per 100 feet of line (200 feet wire). Next trace down column under proper separation until a number equal to this or larger is found. In the same horizontal line and at the left under B. & S. will be found the gauge number of the wire to be used.

For three-phase systems, if great accuracy is required, divide volts to be lost by 0.86 before proceeding with the rest. Select no wire unless its carrying capacity is equal to the amperage required.

Aluminum Wire Carrying Capacities			Direct Current and 25 Cycle Alternating — Separation in Inches									
R. I.	O. I.	B. & S.	D. C.	½	3	6	12	24	36	48	60	72
12	17	14	1.23	1.34	1.34	1.34	1.34	1.34	1.34	1.34	1.34	1.34
17	21	12	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95
21	25	10	3.11	3.16	3.16	3.16	3.15	3.15	3.15	3.15	3.15	3.15
29	42	8	4.95	5.01	5.00	4.99	4.98	4.97	4.96	4.96	4.96	4.96
42	59	6	7.85	8.00	7.98	7.97	7.96	7.95	7.94	7.93	7.92	7.92
46	67	5	9.90	10.11	10.1	10.07	10.05	10.03	10.02	10.01	10.0	9.9
59	76	4	12.40	12.7	12.6	12.6	12.5	12.5	12.5	12.4	12.4	12.4
67	84	3	15.70	15.9	15.8	15.8	15.7	15.7	15.6	15.6	15.5	15.4
76	105	2	19.80	21.2	20.9	20.6	20.5	20.4	20.3	20.2	20.2	20.2
84	126	1	25.10	25.6	25.2	24.9	24.6	24.4	24.3	24.2	24.1	24.0
105	168	0	31.50	32.1	31.4	31.1	30.7	30.3	29.9	29.8	29.7	29.6
126	189	00	39.80	40.5	38.9	38.6	37.7	37.2	36.8	36.4	36.2	36.1
147	231	000	50.20	51.0	48.8	47.7	46.5	45.3	44.6	44.1	43.7	43.4
189	273	0000	63.30	64.3	60.3	58.4	56.5	54.3	53.3	52.4	51.8	51.6
202	294	250000	72.40	....	69.9	67.4	64.5	61.5	60.1	58.7	57.9	57.3
231	336	300000	86.90	....	79.9	75.9	72.3	68.4	66.4	64.7	63.6	62.7
252	378	350000	102.0	....	91.1	86.1	81.1	76.1	72.8	71.1	69.7	68.5
273	420	400000	116.3	....	101.7	95.2	88.7	82.2	78.5	76.5	74.6	72.8
336	504	500000	144.9	....	120.5	110.7	101.1	91.7	87.7	84.2	82.2	80.6

Economy of Conductors.—Any system of electrical conductors may be designed with reference to any of the following conditions:

1. The conductors may be designed for minimum first cost, regardless of waste or quality of service.
2. The conductors may be designed for the best possible service regardless of cost.
3. The conductors may be designed for a minimum cost of generating plant.
4. The conductors may be designed for maximum general economy of operation and installation; i.e., to yield the most profitable results in the long run.
5. The conductors may be designed for a minimum first cost of generating plant and conductors.

The first problem is solved by selecting the smallest wire allowed, either by heating limitations, or mechanical considerations.

The second problem is solved by selecting very large wires, thus reducing the loss to any desired minimum.

The third condition is fulfilled by selecting such large wires that the generator will not be called upon to deliver much waste power.

The fourth problem has heretofore required some very extensive and elaborate calculations, but with the tables following, these have been reduced to a minimum and can be made in a few moments. This is, moreover, a subject which has been very much neglected, especially in connection with short runs such as are used inside of buildings, or to connect one building with another. The general practice has been to figure on a loss of from 2 to 5 per cent, or to disregard all question of economy and work from the standpoint of minimum first cost entirely.

It must be understood that a certain loss in electrical transmission is unavoidable, and that the nearer we approach to an efficiency of 100 per cent the more copper proportionately will be required to reduce the

remaining loss. For instance, if we have a certain wire causing a loss of 10 per cent, by adding another wire just like it we reduce our loss to 5 per cent; by adding two more similar wires we reduce the loss only $2\frac{1}{2}$ per cent more, and by adding four more wires of the same size we gain only $1\frac{1}{4}$ per cent more. In other words, the original wire was capable of transmitting 90 per cent of our energy; two wires 95 per cent, four wires $97\frac{1}{2}$ per cent, and eight wires $98\frac{3}{4}$ per cent. That under such circumstances it is easy to spend more in trying to save the energy than it is worth, is evident. It has been shown by Sir Wm. Thompson and others that the most economical loss is that at which the annual value of the energy lost equals the interest charge on the cost of line construction necessary to save it. In making calculations on this subject we need have nothing to do with the total length of line, or even the total cost of the line; we need be concerned only with the difference in cost between installing any convenient length of the smallest wire permissible, and that of substituting a larger wire. In some cases this may cause no other expense except that of the larger wire, in other cases it may be necessary to reconstruct the whole line in order to make room for larger wires.

The basis of the following tables is found in the proposition and formula below:

$$\left(\frac{R}{1000\times c}-\frac{r}{1000\times c}\right)\times I^{2}\times p\times h=$$

the maximum capital which may economically be invested to substitute a larger wire in place of the smallest permissible wire where:

R equals the resistance of the smallest wire considered,

r the resistance of the larger wire to be considered,

c the interest rate applicable (governed by the number of years line is to remain in use),

I the current to be transmitted,

p the rate per K. W. and

h the number of hours I is used per year.

In connection with this formula we need not consider the whole length of line, but may take any convenient portion of it; therefore, in these tables a run of 100 feet (200 feet of wire) is taken as the basis of all calculations.

The rate of interest applicable in this formula is the following: If line is to be in use only one year it must pay a dividend of 106 per cent; two years, 56; three years, 40; four years, 32; five years, 27; six years, 24; seven years, 21½; eight years, about 20, and nine years, 18¾ per year.

In table CXVIII the values have been calculated for all of the wire sizes given, I^2 can be easily calculated and p and h can be found, for many values thereof, in table CXIX. The figures in table CXVIII have all been carried out to seven decimal points in order to simplify the comparison of small wires with the larger ones, and also to obtain greater accuracy. In most cases, however, when comparing small wires, it will not be necessary to use the full figures, and one or more figures at the right may be dropped.

In using the tables it will be best to first find the quantity $(I^2 \times p \times h)$, as this is fixed in any given problem. Next determine the smallest wire permissible, either on account of safety rules, mechanical considerations, or perhaps because it is already installed. Note the number given in horizontal line in which the B & S gauge number is found and under the column pertaining to the number of years line is to remain in service; from this number subtract the corresponding number pertaining to some larger wire and with the remainder multiply the quantity I p h

previously determined. This will give us the sum in dollars which may economically be invested to substitute the larger wire in place of the smaller. Bear in mind that this is only for a length of run of 100 feet. Example: We wish to find whether it will be profitable to substitute a No. 6 wire in place of a No. 14 carrying a load of 15 amperes, the rate per K. W. being 3 cents, the current to be used 1000 hours per year, and the line assumed to remain in use five years, at the end of which time it will be worthless. Three cents times 1000 hours gives us \$30.00; this multiplied by 225 (I^2) gives us 6750. We now subtract .0002944 (No. 6) from .0018229 (No. 14), which leaves us (omitting the last three decimals) .0016; multiplying 6750 by this, we have 10.8, which is the number of dollars we may spend to install a No. 6 instead of a No. 14 wire. The difference in cost between a No. 14 and a No. 6 is from about ten to twelve dollars, not figuring the cost of supports.

The foregoing calculations are assumed to be made from the standpoint of an engineer who connects onto an established system and who is responsible only for the actual loss in watts occurring on his part of the line. Sometimes, however, a line must be laid out from the central station, and the point then is not only the wattage loss, but also the loss in generator capacity. In this connection the length of the line is the principal consideration, and it becomes a question whether it is cheaper to provide a certain excess capacity in the generator and allow this to be lost in a small transmission line, or to provide a heavier line and use the generator pressure more economically. In lines of this character boosters are usually resorted to to regulate the pressure.

The standard central station system usually soon evolves into an interconnected system of wires in which no accurate calculations on loss can be made.

TABLE CXVIII

To find the maximum amount of capital which may be economically invested to substitute a larger conductor for the smallest one permissible for a run of 100 feet, select smallest wire permissible and note number given in column headed by number of years line is assumed to remain in use. From this number subtract that of a larger wire in same vertical column and with the remainder multiply square of current times cost of 1 K. W. for number of hours line is assumed to be used per year.

B. &. S.	1 year	2 years	3 years	4 years	5 years	6 years	7 years	8 years	9 years
14	.0004800	.0009786	.0012710	.0015887	.0018829	.0021184	.0023646	.0025676	.0027187
12	.0003013	.0005703	.0007985	.0009982	.0011829	.0013309	.0015786	.0016131	.0017080
10	.0001902	.0003600	.0005040	.0006300	.0007466	.0008400	.0009376	.0010181	.0010780
8	.0001183	.0002239	.0003135	.0003918	.0004644	.0005225	.0005832	.0006333	.0006706
6	.0000750	.0001419	.0001887	.0002480	.0002944	.0003313	.0003697	.0004015	.0004251
5	.0000595	.0001126	.0001577	.0001971	.0002336	.0002628	.0002933	.0003185	.0003372
4	.0000472	.0000893	.0001250	.0001562	.0001852	.0002083	.0002325	.0002525	.0002674
3	.0000373	.0000707	.0000990	.0001238	.0001466	.0001650	.0001842	.0002000	.0002117
2	.0000296	.0000561	.0000785	.0000981	.0001162	.0001334	.0001460	.0001585	.0001679
1	.0000237	.0000450	.0000630	.0000787	.0000933	.0001050	.0001172	.0001272	.0001347
0	.0000188	.0000357	.0000500	.0000625	.0000741	.0000833	.0000930	.0001010	.0001069
00	.0000149	.0000282	.0000395	.0000494	.0000580	.0000658	.0000734	.0000798	.0000845
000	.0000119	.0000225	.0000315	.0000396	.0000466	.0000525	.0000586	.0000636	.0000673
0000	.0000094	.0000179	.0000250	.0000312	.0000370	.0000417	.0000465	.0000505	.0000534
300000	.0000067	.0000126	.0000177	.0000222	.0000263	.0000296	.0000330	.0000358	.0000379
400000	.0000050	.0000094	.0000132	.0000165	.0000196	.0000221	.0000246	.0000267	.0000283
500000	.0000039	.0000075	.0000105	.0000132	.0000155	.0000175	.0000195	.0000212	.0000224
600000	.0000033	.0000063	.0000088	.0000110	.0000128	.0000146	.0000163	.0000176	.0000187
700000	.0000028	.0000053	.0000075	.0000093	.0000110	.0000125	.0000139	.0000151	.0000160
800000	.0000025	.0000047	.0000066	.0000081	.0000095	.0000108	.0000121	.0000131	.0000139
900000	.0000022	.0000042	.0000060	.0000075	.0000090	.0000100	.0000111	.0000121	.0000128
1000000	.0000020	.0000038	.0000052	.0000066	.0000077	.0000087	.0000097	.0000106	.0000112

TABLE CXIX

Economy of Conductors

Table shows products of various rates per K.W. **multiplied** by number of hours used per year.

Hours used per year	Rates per K.W. ½	1	1½	2	2½	3	4	5	6	7	8	10
100	.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	7.0	8.0	10.0
200	1.	2.0	3.0	4.0	5.0	6.0	8.0	10.0	12.0	14.0	16.0	20.0
300	1.5	3.0	4.5	6.0	7.5	9.0	12.0	15.0	18.0	21.0	24.0	30.0
400	2.0	4.0	6.0	8.0	10.0	12.0	16.0	20.0	24.0	28.0	32.0	40.0
500	2.5	5.0	7.5	10.0	12.5	15.0	20.0	25.0	30.0	35.0	40.0	50.0
600	3.0	6.0	9.0	12.0	15.0	18.0	24.0	30.0	36.0	42.0	48.0	60.0
700	3.5	7.0	10.5	14.0	17.5	21.0	28.0	35.0	42.0	49.0	56.0	70.0
800	4.0	8.0	12.0	16.0	20.0	24.0	32.0	40.0	48.0	56.0	64.0	80.0
900	4.5	9.0	13.5	18.0	22.5	27.0	36.0	45.0	54.0	63.0	72.0	90.0
1000	5.0	10.0	15.0	20.0	25.0	30.0	40.0	50.0	60.0	70.0	80.0	100.0
1500	7.5	15.0	22.5	30.0	37.5	45.0	60.0	75.0	90.0	105.0	120.0	150.0
2000	10.0	20.0	30.0	40.0	50.0	60.0	80.0	100.0	120.0	140.0	160.0	200.0
3000	15.0	30.0	45.0	60.0	75.0	90.0	120.0	150.0	180.0	210.0	240.0	300.0

TABLE CXX

Copper Wire Table

Bureau of Standards, Washington, D. C.

Working Table, International Standard Annealed Copper American Wire Gauge (B. & S.)

Gauge No.	Diam. in Mils	Cross Section Circular Mils	Cross Section Square Inches	Ohms per 1000 Feet 25° C (=77° F)	Ohms per 1000 Feet 65° C (=149° F)	Pounds per 1000 Feet
0000	460.	212 000.	0.166	0.0500	0.0577	641.
000	410.	168 000.	.132	.0630	.0727	508.
00	365.	133 000.	.105	.0795	.0917	403.
0	325.	106 000.	.0829	.100	.116	319.
1	289.	83 700.	.0657	.126	.146	253.
2	258.	66 400.	.0521	.159	.184	201.
3	229.	52 600.	.0413	.201	.232	159.
4	204.	41 700.	.0328	.253	.292	126.
5	182.	33 100.	.0260	.319	.369	100.
6	162.	26 300.	.0206	.403	.465	79.5
7	144.	20 800.	.0164	.508	.586	63.0
8	128.	16 500.	.0130	.641	.739	50.0
9	114.	13 100.	.0103	.808	.932	39.6
10	102.	10 400.	.008 15	1.02	1.18	31.4
11	91.	8230.	.006 47	1.28	1.48	24.9
12	81.	6530.	.005 13	1.62	1.87	19.8
13	72.	5180.	.004 07	2.04	2.36	15.7
14	64.	4110.	.003 23	2.58	2.97	12.4
15	57.	3260.	.002 56	3.25	3.75	9.86
16	51.	2580.	.002 03	4.09	4.73	7.82
17	45.	2050.	.001 61	5.16	5.96	6.20
18	40.	1620.	.001 28	6.51	7.51	4.92
19	36.	1290.	.001 01	8.21	9.48	3.90
20	32.	1020.	.000 802	10.4	11.9	3.09
21	28.5	810.	.000 636	13.1	15.1	2.45

TABLE CXX—Continued

Gauge No.	Diam. in Mils	Cross Section Circular Mils	Cross Section Square Inches	Ohms per 1000 Feet 25° C (=77° F)	Ohms per 1000 Feet 65° C (=149° F)	Pounds per 1000 Feet
22	25.3	642.	.000 505	16.5	19.0	1.94
23	22.6	509.	.000 400	20.8	24.0	1.54
24	20.1	404.	.000 317	26.2	30.2	1.22
25	17.9	320.	.000 252	33.0	38.1	0.970
26	15.9	254.	.000 200	41.6	48.0	.769
27	14.2	202.	.000 158	52.5	60.6	.610
28	12.6	160.	.000 126	66.2	76.4	.484
29	11.3	127.	.000 099 5	83.4	96.3	.384
30	10.0	101.	.000 078 9	105.	121.	.304
31	8.9	79.7	.000 062 6	133.	153.	.241
32	8.0	63.2	.000 049 6	167.	193.	.191
33	7.1	50.1	.000 039 4	211.	243.	.152
34	6.3	39.8	.000 031 2	266.	307.	.120
35	5.6	31.5	.000 024 8	335.	387.	.0954
36	5.0	25.0	.000 019 6	423.	488.	.0757
37	4.5	19.8	.000 015 6	533.	616.	.0600
38	4.0	15.7	.000 012 3	673.	776.	.0476
39	3.5	12.5	.000 009 8	848.	979.	.0377
40	3.1	9.9	.000 007 8	1070.	1230.	.0299

Note. 1.—The table is based on the international standard of resistance for copper, which takes the fundamental mass resistivity = 0.15328 ohm (meter, gram) at 20° C, the corresponding temperature coefficient = 0.00393 at 20° C, and the density = 8.89 grams per cc at 20° C. The temperature coefficient is proportional to the conductivity, whence the change of mass resistivity per degree C is a constant, 0.000597 ohm (meter, gram).

Note 2.—The values given in the table are only for annealed copper of the standard resistivity. The user of the table must apply the proper correction for copper of any other resistivity. Hard-drawn copper may be taken as about 2.7 per cent higher resistivity than annealed copper.

Note 3.—Ohms per mile, or pounds per mile, may be obtained by multiplying the respective values above by 5.28.

Note 4.—For complete tables and other data see Circular No. 31 of the Bureau of Standards.

Bureau of Standards, Washington, D. C., 1914

TABLE CXXI

Bare Concentric-Lay Cables of Standard Annealed Copper

Bureau of Standards, Washington, D. C.

Size of Cable		Ohms per 1000 Feet		Pounds per 1000 ft.	Standard Concentric Stranding			Flexible Concentric Stranding		
Circular Mils	A.W.G. No.	25° C (=77° F)	65° C (=149° F)		Number of Wires	Diam. of Wires, in Mils	Outside Diam., in Mils	Number of Wires	Diam. of Wires, in Mils	Outside Diam., in Mils
2 000 000		0.005 39	0.006 22	6180.	127	125.5	1631.	169	108.8	1632.
1 900 000		.005 68	.006 55	5870.	127	122.3	1590.	169	106.0	1590.
1 800 000		.005 99	.006 92	5560.	127	119.1	1548.	169	103.2	1548.
1 700 000		.006 34	.007 32	5250.	127	115.7	1504.	169	100.3	1504.
1 600 000		.006 74	.007 78	4940.	127	112.2	1459.	169	97.3	1460.
1 500 000		.007 19	.008 30	4630.	91	128.4	1412.	127	108.7	1413.
1 400 000		.007 70	.008 89	4320.	91	124.0	1364.	127	105.0	1365.
1 300 000		.008 30	.009 58	4010.	91	119.5	1315.	127	101.2	1315.
1 200 000		.008 99	.0104	3710.	91	114.8	1263.	127	97.2	1264.
1 100 000		.009 81	.0114	3400.	91	109.9	1209.	127	93.1	1210.
1 000 000		.0108	.0124	3090.	61	128.0	1152.	91	104.8	1153.
950 000		.0114	.0131	2930.	61	124.8	1123.	91	102.2	1124.
900 000		.0120	.0138	2780.	61	121.5	1093.	91	99.4	1094.
850 000		.0127	.0146	2620.	61	118.0	1062.	91	96.6	1063.

TABLE CXXI—Continued

Size of Cable Circular Mils	Size of Cable A.W.G. No.	Ohms per 1000 Feet 25° C (=77° F)	Ohms per 1000 Feet 65° C (=149° F)	Pounds per 1000 ft.	Standard Concentric Stranding Number of Wires	Standard Concentric Stranding Diam. of Wires, in Mils	Standard Concentric Stranding Outside Diam., in Mils	Flexible Concentric Stranding Number of Wires	Flexible Concentric Stranding Diam. of Wires, in Mils	Flexible Concentric Stranding Outside Diam., in Mils
800 000		.0135	.0156	2470.	61	114.5	1031.	91	93.8	1031.
750 000		.0144	.0166	2320.	61	110.9	998.	91	90.8	999.
700 000		.0154	.0178	2160.	61	107.1	964.	91	87.7	965.
650 000		.0166	.0192	2010.	61	103.2	929.	91	84.5	930.
600 000		.0196	.0207	1185.	61	99.2	893.	91	81.2	893.
550 000		.0196	.0226	1700.	61	95.0	855.	91	77.7	855.
500 000		.0216	.0249	1540.	37	116.2	814.	61	90.5	815.
450 000		.0240	.0277	1390.	37	110.3	772.	61	85.9	773.
400 000		.0270	.0311	1240.	37	104.0	728.	61	81.0	729.
350 000		.0308	.0356	1080.	37	97.3	681.	61	75.7	682.
300 000		.0360	.0415	926.	37	90.0	630.	61	70.1	631.
250 000		.0431	.0498	772.	37	82.2	575.	61	64.0	576.
212 000	0000	.0509	.0587	653.	19	105.5	528.	37	75.6	533.
168 000	000	.0652	.0741	518.	19	94.0	470.	37	67.3	471.
133 000	00	.0811	.0936	411.	19	83.7	418.	37	60.0	420.
106 000	0	.102	.117	326.	19	74.5	373.	37	53.4	374.
83 700	1	.129	.149	258.	19	66.4	332.	37	47.6	333.
66 400	2	.162	.187	205.	7	97.4	292.	19	59.1	296.
52 600	3	.205	.237	163.	7	86.7	260.	19	52.6	263.

TABLE CXXI—Continued

Size of Cable Circular Mils	Size of Cable A.W.G. No.	Ohms per 1000 Feet 25° C (=77° F)	Ohms per 1000 Feet 65° C (=149° F)	Pounds per 1000 ft.	Standard Concentric Stranding Number of Wires	Standard Concentric Stranding Diam. of Wires, in Mils	Standard Concentric Stranding Outside Diam., in Mils	Flexible Concentric Stranding Number of Wires	Flexible Concentric Stranding Diam. of Wires, in Mils	Flexible Concentric Stranding Outside Diam., in Mils
41 700	4	.259	.299	129.	7	77.2	232.	19	46.9	234.
33 100	5	.326	.376	102.	7	68.8	206.	19	41.7	209.
26 300	6	.410	.473	81.0	7	61.2	184.	19	37.2	186.
20 800	7	.519	.599	64.3	7	54.5	164.	19	33.1	166.
16 500	8	.654	.755	51.0	7	48.6	146.	19	29.5	147.

Note 1.—The fundamental resistivity used in calculating the table is the International Annealed Copper Standard, viz., 0.15328 ohm (meter, gram) at 20° C (increased by 2 per cent as explained in Note 2 and on P. —). The temperature coefficient is given in Table —. The density is 8.89 grams per cubic centimeter.

Note 2.—This table is in accord with standards adopted by the Standards Committee of the American Institute of Electrical Engineers, both in respect to the "Number of wires" and in respect to the correction for increase of resistance and mass due to the twist of the wires. The values given for "Ohms per 1000 feet" and "Pounds per 1000 feet" are 2 per cent greater than for a solid rod of cross section equal to the total cross section of the wires of the cable. This increment of 2 per cent means that the values are correct for cables having a lay of 1 in 15.7. For any other lay, equal to 1 in n, resistance or mass may be calculated by increasing the above tabulated values by

$$\left(\frac{493.}{n^2} - 2.\right)\%.$$

TABLE CXXII

Aluminum Company of America

Stranded Aluminum Wire

Diameter and Properties

Conductivity at 62 in the Matthiessen Standard Scale

		DIAMETERS		WEIGHT IN POUNDS			
Number B. & S. Gauge	Circular Mils.	Decimal Parts of an Inch.	Nearest 32nd of an Inch.	BARE Per 1000 Feet.	BARE Per Mile.	Triple Braid Insulated Per 1000 Feet.	Resistance in Ohms. at 70° F per 1000 Ft.
....	1000000	1.152	$1\frac{5}{32}$	920.	4858.	1406.	.016726
....	950000	1.125	$1\frac{1}{8}$	874.	4617.	1337.	.017606
....	900000	1.092	$1\frac{3}{32}$	828.	4374.	1268.	.018585
....	850000	1.062	$1\frac{1}{16}$	782.	4131.	1199.	.019679
....	800000	1.035	$1\frac{1}{32}$	736.	3888.	1129.	.020907
....	750000	.996	1	690.	3645.	1060.	.022301
....	700000	963	$\frac{31}{32}$	644.	3402.	990.	.023894
....	650000	.928	$\frac{15}{16}$	598.	3159.	921.	.025734
....	600000	.891	$\frac{29}{32}$	552.	2916.	852.	.027878
....	550000	.854	$\frac{27}{32}$	506.	2673.	782.	.030411
....	500000	.814	$\frac{13}{16}$	460.	2430.	713.	.033450
....	450000	.772	$\frac{25}{32}$	414.	2187.	644.	.037170
....	400000	.725	$\frac{23}{32}$	368.	1944.	575.	.041818
....	350000	.679	$\frac{11}{16}$	322.	1701.	506.	.047789
....	300000	.621	$\frac{5}{8}$	276.	1458.	436.	.055755
....	250000	.567	$\frac{9}{16}$	230.	12.15	366.	.066905
0000	211600	.522	$\frac{17}{32}$	195.	1028.	313.	.079045
000	167805	.464	$\frac{15}{32}$	155.	816.	253.	.099675
00	133079	.414	$\frac{13}{32}$	123.	647.	204.	.12569
0	105534	.368	$\frac{3}{8}$	97.	513.	165.	.15849
1	83694	.328	$\frac{11}{32}$	77.	407.	135.	.19984
2	66373	.291	$\frac{9}{32}$	61.	323.	112.	.25200
3	52634	.261	$\frac{1}{4}$	48.5	256.	93.5	.31779
4	41742	.231	$\frac{7}{32}$	38.5	203.	76.5	.40069
5	33102	.206	$\frac{7}{32}$	30.2	161.	56.0	.50530
6	26250	.180	$\frac{3}{16}$	24.1	128.	47.0	.63720

TABLE CXXIII

Aluminum Company of America

Weight of Aluminum, Wrought Iron, Steel, Copper and Brass Wire.

Diameters determined by American (Brown & Sharpe) Gauge.

Water at 62° Fahrenheit, 62.355 lbs. per cubic foot.

Drawn Wrought Iron is 2.8724 times heavier than Drawn Aluminum.
" Steel " 2.9322 " " " " "
" Copper " 3.3321 " " " " "
" Brass " 3.1900 " " " " "

No. of Gauge	Size of each No. Inch	Ft. per lb. Aluminum Feet	Weight of Wire per 1000 Lineal Feet: Aluminum Lbs.	Wro't Iron Lbs.	Steel Lbs.	Copper Lbs.	Brass Lbs.
0000	.46000	5.185	192.86	553.97	565.50	642.68	615.21
000	.40964	6.539	152.94	439.33	448.45	509.32	487.92
00	.36480	8.246	121.28	348.40	355.65	404.20	386.94
0	.32486	10.396	96.18	276.30	282.02	320.50	306.83
1	.28930	13.108	76.29	219.11	223.68	254.20	243.35
2	.25763	16.529	60.50	173.78	177.38	201.60	192.98
3	.22942	20.846	47.97	137.80	140.67	159.86	153.02
4	.20431	26.281	38.05	109.28	111.57	126.78	121.37
5	.18194	33.146	30.17	86.68	88.46	100.54	96.26
6	.16202	41.789	23.93	68.73	70.15	79.72	76.32
7	.14428	52.687	18.98	54.43	55.56	63.23	60.53
8	.12849	66.445	15.05	43.23	44.12	50.14	48.00
9	.11443	83.822	11.93	34.28	34.99	39.77	38.07
10	.10189	105.68	9.462	27.18	27.74	31.53	30.18
11	.090742	133.24	7.505	21.56	22.01	25.01	23.94
12	.080808	168.01	5.952	17.10	17.46	19.83	18.99
13	.071961	211.86	4.720	13.56	13.84	15.73	15.06
14	.064084	267.17	3.743	10.75	10.98	12.47	11.94

TABLE CXXIII—Continued

No. of Gauge	Size of each No. Inch	Ft. per lb. Aluminum Feet	Weight of Wire per 1000 Lineal Feet — Aluminum Lbs.	Wro't Iron Lbs.	Steel Lbs.	Copper Lbs.	Brass Lbs.
15	.057068	336.93	2.968	8.526	8.704	9.890	9.468
16	.050820	424.81	2.354	6.761	6.903	7.843	7.508
17	.045257	535.62	1.867	5.362	5.474	6.220	5.955
18	.040303	675.67	1.480	4.252	4.342	4.933	4.723
19	.035890	851.79	1.174	3.372	3.443	3.912	3.755
20	.031961	1074.11	.9310	2.672	2.730	3.102	2.970
21	.028462	1356.	.7382	2.121	2.165	2.460	2.355
22	.025347	1707.94	.5855	1.682	1.717	1.951	1.868
23	.022571	2153.78	.4643	1.333	1.361	.547	1.481
24	.020100	2715.91	.3682	1.058	1.080	1.227	1.175
25	.017900	3424.66	.2920	.8388	.8563	.9731	.9316
26	.015940	4317.78	.2316	.6652	.6791	.7716	.7387
27	.014195	5446.63	.1836	.5276	.5385	.6120	.5858
28	.012641	6868.13	.1456	.4183	.4270	.4853	.4645
29	.011257	8657.5	.1155	.3317	.3386	.3849	.3683
30	.010025	10917.0	.0916	.2631	.2686	.3052	.2922
31	.008928	13762.8	.0727	.2087	.2130	.2421	.2318
32	.007950	17361.1	.0576	.1655	.1693	.1919	.1837
33	.007080	21886.7	.0457	.1312	.1340	.1522	.1457
34	.006304	27622.	.0362	.1040	.1062	.1207	.1155
35	.005614	34807.3	.0287	.0825	.0842	.0957	.0916
36	.005000	43878.9	.0228	.0655	.0668	.0759	.0727
37	.004453	55245.	.0181	.0519	.0530	.0602	.0577
38	.003965	69783.7	.0143	.0413	.0420	.0478	.0457
39	.003531	88028.2	.0114	.0326	.0333	.0379	.0363
40	.003144	110980.	.0090	.0259	.0264	.0300	.0287
Specific gravity Wire...			2.680	7.698	7.858	8.930	8.549
Wt., per cu. ft., Wire..			167.111	480.000	490.000	556.830	533.073

TABLE CXXIV

Circular of the Bureau of Standards

Hard-Drawn Aluminum Wire at 20° C (or, 68° F)

Bureau of Standards, Washington, D. C.

American Wire Gauge (B. & S.)

Gauge No.	Diameter in Mils	Cross Section: Circular Mils	Cross Section: Square Inches	Ohms per 1000 Feet	Pounds per 1000 Feet	Pounds per Ohm	Feet per Ohm
0000	460.	212 000.	0.166	0.0804	195.	2420.	12 400.
000	410.	168 000.	.132	.101	154.	1520.	9860.
00	365.	133 000.	.105	.128	122.	957.	7820.
0	325.	106 000.	.0829	.161	97.0	602.	6200.
1	289.	83 700.	.0657	.203	76.9	379.	4920.
2	258.	66 400.	.0521	.256	61.0	238.	3900.
3	229.	52 600.	.0413	.323	48.4	150.	3090.
4	204.	41 700.	.0328	.408	38.4	94.2	2450.
5	182.	33 100.	.0260	.514	30.4	59.2	1950.

TABLE CXXIV—Continued

Gauge No.	Diameter in Mils	Cross Section: Circular Mils	Cross Section: Square Inches	Ohms per 1000 Feet	Pounds per 1000 Feet	Pounds per Ohm	Feet per Ohm
6	162.	26 300.	.0206	.648	24.1	37.2	1540.
7	144.	20 800.	.0164	.817	19.1	23.4	1220.
8	128.	16 500.	.0130	1.03	15.2	14.7	970.
9	114.	13 100.	.0103	1.30	12.0	9.26	770.
10	102.	10 400.	.008 15	1.64	9.55	5.83	610.
11	91.	8230.	.006 47	2.07	7.57	3.66	484.
12	81.	6530.	.005 13	2.61	6.00	2.30	384.
13	72.	5180.	.004 07	3.29	4.76	1.45	304.
14	64.	4110.	.003 23	4.14	3.78	0.911	241.
15	57.	3260.	.002 56	5.22	2.99	.573	191.
16	51.	2580.	.002 03	6.59	2.37	.360	152.
17	45.	2050.	.001 61	8.31	1.88	.227	120.
18	40.	1620.	.001 28	10.5	1.49	.143	95.5
19	36.	1290.	.001 01	13.2	1.18	.0897	75.7
20	32.	1020.	.000 802	16.7	0.939	.0564	60.0
21	28.5	810.	.000 636	21.0	.745	.0355	47.6
22	25.3	642.	.000 505	26.5	.591	.0223	37.8
23	22.6	509.	.000 400	33.4	.468	.0140	29.9

TABLE CXXIV—Continued

Gauge No.	Diameter in Mils	Cross Section Circular Mils	Cross Section Square Inches	Ohms per 1000 Feet	Pounds per 1000 Feet	Pounds per Ohm	Feet per Ohm
24	20.1	404.	.000 317	42.1	.371	.008 82	23.7
25	17.9	320.	.000 252	53.1	.295	.005 55	18.8
26	15.9	254.	.000 200	67.0	.234	.003 49	14.9
27	14.2	202.	.000 158	84.4	.185	.002 19	11.8
28	12.6	160.	.000 126	106.	.147	.001 38	9.39
29	11.3	127.	.000 099 5	134.	.117	.000 868	7.45
30	10.0	101.	.000 078 9	169.	.0924	.000 546	5.91
31	8.9	79.7	.000 062 6	213.	.0733	.000 343	4.68
32	8.0	63.2	.000 049 6	269.	.0581	.000 216	3.72
33	7.1	50.1	.000 039 4	339.	.0461	.000 136	2.95
34	6.3	39.8	.000 031 2	428.	.0365	.000 085 4	2.34
35	5.6	31.5	.000 024 8	540.	.0290	.000 053 7	1.85
36	5.0	25.0	.000 019 6	681.	.0230	.000 033 8	1.47
37	4.5	19.8	.000 015 6	858.	.0182	.000 021 2	1.17
38	4.0	15.7	.000 012 3	1080.	.0145	.000 013 4	0.924
39	3.5	12.5	.000 009 79	1360.	.0115	.000 008 40	.733
40	3.1	9.9	.000 007 77	1720.	.0091	.000 005 28	.581

Copper Clad Steel Wire

Copper Clad Wire is made by welding molten copper to a steel billet. This copper clad billet is then hot-rolled to a ⅜-inch rod and cold-drawn into wire under a process similar to that of copper and other wire.

It is absolutely rustproof, possesses greater strength than copper, and is less expensive.

Comparative Characteristics of Copper and Copper Clad

Size B. & S.	Weight, Lbs. Per Mile: Copper Clad	Weight, Lbs. Per Mile: Copper	Approximate Elastic Limit: Copper Clad	Approximate Elastic Limit: Copper	Approximate Breaking Weight, Lbs.: Copper Clad	Approximate Breaking Weight, Lbs.: Copper	Av. Resistance Int. Ohms per Mile at 75° Fahr. — Copper Clad — 30% Grade Max. 27%	30% Grade Av. 30%	40% Grade Max. 35%	40% Grade Av. 40%	Copper
0000	3140	3378	5000	2770	10000	8310	1	.90	.77	.67	.27
000	2490	2678	4150	2190	8300	6580	1.26	1.13	.97	.85	.34
00	1975	2124	3420	1740	6850	5226	1.59	1.43	1.23	1.07	.43
0	1570	1685	2850	1520	5700	4558	2	1.80	1.54	1.35	.54
1	1240	1336	2400	1250	4800	3746	2.55	2.30	1.97	1.72	.69
2	985	1059	2000	1040	4000	3127	3.19	2.87	2.46	2.15	.86
3	780	840.1	1600	830	3200	2480	4.04	3.63	3.11	2.72	1.09
4	620	666.3	1300	650	2600	1967	5.07	4.57	3.91	3.43	1.37
5	491	528.2	1100	520	2200	1559	6.40	5.77	4.94	4.33	1.73
6	390	419	900	410	1800	1237	8.07	7.26	6.23	5.45	2.18
7	309	332.4	720	330	1450	980	10.22	9.20	7.88	6.90	2.76
8	245	263.6	600	260	1200	778	12.92	11.63	9.97	8.73	3.49
9	194	208.9	480	210	975	617	16.26	14.63	12.54	10.97	4.39
10	154	165.8	400	160	800	489	20.33	18.30	15.68	13.72	5.49
11	122	131.3	325	130	650	388	25.55	23	19.71	17.25	6.90
12	97	104.2	250	100	510	307	32.22	29	24.85	21.75	8.70
13	77	82.7	200	80	410	244	40.78	36.70	31.45	27.57	11.01
14	61	65.5	165	60	320	193	51.63	46.47	39.83	34.85	13.94

It will be noted that, owing to the difference in specific gravities, there is a saving of about 7 per cent in copper clad over copper wire of the same size and length.

We have given above, under each grade, two columns of resistances, the first giving the maximum allowable resistance of any coil, and the second the average resistance of the material furnished in that grade. For practical purposes and line calculations, the average resistance is the figure that should be used

TABLE CXXVI

Comparative Weights of Copper Clad and Copper Weatherproof Wire.

Size B. & S.	Double Braid, Per 1000 Feet, Copper Clad	Double Braid, Per 1000 Feet, Copper	Double Braid, Per Mile, Copper Clad	Double Braid, Per Mile, Copper	Triple Braid, Per 100 Feet, Copper Clad	Triple Braid, Per 100 Feet, Copper	Triple Braid, Per Mile, Copper Clad	Triple Braid, Per Mile, Copper
0000	678	723	3578	3817	722	767	3811	4050
000	551	587	2909	3098	593	629	3131	3320
00	439	467	2317	2467	473	502	2500	2650
0	354	377	1870	1989	385	407	2031	2150
1	276	294	1458	1553	298	316	1575	1670
2	225	239	1189	1264	245	260	1295	1370
3	174	185	918	977	188	199	991	1050
4	142	151	748	795	155	164	818	865
5	115	122	608	646	127	135	673	710
6	94.5	100	499	529	106	112	560	590
8	62.5	66	330	349	71.25	75	376	395
9	50.75	54	268	283	58.75	62	310	325
10	43.5	46	229	241	50.75	53	268	280
12	28.5	30	151	158	33.75	35	178	185
14	19.5	20	102	107	24.00	25	127	130

An allowable variation of 3 per cent on either side is understood.

TABLE CXXVII

18% German Silver Resistance Wire.

No. B. & S. Gauge	Diam. Ins.	Area C. M.	Resistance per 1000 Ft. at 75° F.	Weight Lbs. per 1000 Ft. Bare	Ohms Per Lb.
0	.325	105,625	1.95	302	.00645
1	.289	83,521	2.53	239	.01025
2	.258	66,564	3.22	190	.0163
3	.229	52,441	4.14	150	.0259
4	.204	41,616	5.18	119	.0412
5	.182	33,124	6.55	95	.0656
6	.162	26,244	8.28	72	.1042
7	.144	20,736	10.47	59	.1657
8	.128	16,384	13.22	47	.2635
9	.114	12,996	16.68	37.6	.4189
10	.102	10,404	20.8	29.2	.6663
11	.091	8,281	26.2	23.7	1.059
12	.081	6,561	33.2	18.8	1.684
13	.072	5,184	42	14.8	2.619
14	.064	4,096	53	11.7	4,258
15	.057	3,249	67	9.3	6.773
16	.051	2,601	84	7.45	10.768
17	.045	2,025	107	5.73	17.121
18	.040	1,600	136	4.57	27.216
19	.036	1,296	168	3.7	43.281
20	.032	1,024	222	2.93	68.838
21	.0285	812.3	270	2.32	109.45
22	.0253	640.1	340	1.83	174.03
23	.0226	510.8	425	1.46	276.78
24	.0201	404.0	540	1.15	439.95
25	.0179	320.4	680	.91	699.72
26	.0159	252.8	864	.72	1,112.4
27	.0142	201.6	1,076	.58	1,768.8
28	.0126	158.8	1,370	.46	2,811.9
29	.0113	127.7	1,700	.365	4,473
30	.010	100.0	2,180	.286	7,011
31	.0089	79.2	2,750	.266	11,306
32	.008	64.0	3,400	.183	17,980
33	.0071	50.4	4,300	.144	28,581
34	.0063	39.7	5,480	.113	45,465
35	.0056	31.4	6,920	.090	72,261
36	.005	25.0	8,700	.071	114,933
37	.0045	20.2	11,000	.058	182,742
38	.004	16.0	13,850	.046	291,270
39	.0035	12.2	17,550	.035	462,000
40	.003	9.0	22,200	.026	887,250

The composition commonly known as German Silver is that containing 18% of nickel. Its resistance varies somewhat in different lots, and according to temper, and is approximately 21 times that of copper.

30% German Silver Wire has a resistance approximately 28 times that of copper.

TABLE CXXVIII

Properties of Galvanized Telephone and Telegraph Wires.

Based on Standard Specifications.

American Steel and Wire Co.

Size B.W.G.	Diam. in Mils	Area in Circular Mils	Approximate wt. in lbs. Per 1000 feet	Per mile	Approximate breaking strain in lbs. Ex. B.B.	B.B.	Steel	Res. per mile (Latent Ohms) at 68° F., 20° C. Ex. B.B.	B.B.	Steel
0	340	115600	313	1655	4138	4634	4965	2.84	3.38	3.93
1	300	90000	244	1289	3223	3609	3867	3.65	4.34	5.04
2	284	80656	218	1155	2888	3234	3465	4.07	4.85	5.63
3	259	67081	182	960	2400	2688	2880	4.90	5.83	6.77
4	238	56644	153	811	2028	2271	2433	5.80	6.91	8.01
5	220	48400	131	693	1732	1940	2079	6.78	8.08	9.38
6	203	41209	112	590	1475	1652	1770	7.97	9.49	11.02
7	180	32400	87	463	1158	1296	1389	10.15	12.10	14.04
8	165	27225	74	390	975	1092	1170	12.05	14.36	16.71
9	148	21904	60	314	785	879	942	14.97	17.84	20.70
10	134	17956	49	258	645	722	774	18.22	21.71	25.29
11	120	14400	39	206	515	577	618	22.82	27.19	31.55
12	109	11881	32	170	425	476	510	27.65	32.94	38.23
13	95	9025	25	129	310	347	372	37.90	45.16	52.41
14	83	6889	19	99	247	277	297	47.48	56.56	65.66
15	72	5184	14	74	185	207	222	63.52	75.68	87.84
16	65	4225	11	61	152	171	183	77.05	91.80	106.55

TABLE CXXIX

Approximate Outside Dimensions of Wires and Cables

The table below is for the use of those who wish to estimate carrying capacities of conductors without cutting into insulation or shutting down a plant. The figures given are thought to be an average for voltage up to 600. Weatherproof dimensions are for minimum thickness allowed by N. E. C.

	Rubber Covered			Weatherproof			Lead Covered		
Circular Mils.	Diameter	Circumference	Wt. per 1000 Ft.	Diameter	Circumference	Wt. per 1000 Ft.	Diameter	Circumference	Wt. per 1000 Ft.
2000000	2 1/8	6 43/64	7200	1 56/64	5 57/64	7008	2 8/64	6 43/64	11300
1750000	2 1/32	6 25/64	6300	1 49/64	5 35/64	6190	2 2/64	6 25/64	10225
1500000	1 7/8	5 57/64	5550	1 42/64	5 13/64	5375	1 60/64	6 6/64	9100
1250000	1 3/4	5 32/64	4700	1 35/64	4 55/64	4500	1 50/64	5 38/64	7950
1000000	1 34/64	4 52/64	3900	1 26/64	4 27/64	3675	1 39/64	5 4/64	6280
950000	1 31/64	4 46/64	3750				1 35/64	4 55/64	6050
900000	1 29/64	4 36/64	3575	1 20/64	4 8/64	3330	1 33/64	4 49/64	5800
850000	1 27/64	4 30/64	3400				1 33/64	4 46/64	5580
800000	1 25/64	4 23/64	3250	1 16/64	3 59/64	3000	1 30/64	4 40/64	5350
750000	1 23/64	4 17/64	3000	1 14/64	3 53/64	2800	1 28/64	4 33/64	5110
700000	1 20/64	4 8/64	2850	1 12/64	3 47/64	2650	1 26/64	4 28/64	4880
650000	1 18/64	4 1/64	2835				1 24/64	4 20/64	4640
600000	1 15/64	3 56/64	2575	1 7/64	3 35/64	2250	1 23/64	4 17/64	4385
550000	1 12/64	3 47/64	2325				1 22/64	4 14/64	4150
500000	1 8/64	3 34/64	2130	1 5/64	3 25/64	1900	1 13/64	3 50/64	3480
450000	1 5/64	3 25/64	1925	61/64	2 63/64	1700	1 12/64	3 47/64	3225
400000	1 2/64	3 18/64	1735	59/64	2 57/64	1550	1 10/64	3 41/64	3000
350000	63/64	3 6/64	1525	56/64	2 48/64	1350	1 5/64	3 25/64	2750
300000	60/64	2 56/64	1360	52/64	2 35/64	1175	1 1/64	3 12/64	2480
250000	57/64	2 51/64	1185	49/64	2 28/64	985	61/64	3	2230
225000	55/64	2 45/64	975						

TABLE CXXX

Approximate Outside Diameter of Wires and Cables Rubber Covered, 0 to 600 Volts

B. & S.	Solid S.B.	Solid D.B.	Stranded S.B.	Stranded D.B.	Wt. per 1000 feet	Duplex Solid	Duplex Stranded
0000	44/64	47/64	49/64	52/64	850	48/64 × 91/64	52/64 × 99/64
000	40/64	43/64	45/64	48/64	700	44/64 × 82/64	48/64 × 92/64
00	37/64	40/64	41/64	44/64	575	41/64 × 77/64	44/64 × 83/64
0	34/64	37/64	38/64	41/64	475	38/64 × 71/64	41/64 × 78/64
1	32/64	35/64	35/64	38/64	375	35/64 × 66/64	38/64 × 72/64
2	28/64	31/64	30/64	33/64	300	31/64 × 58/64	34/64 × 63/64
3	26/64	29/64	28/64	31/64	260	29/64 × 54/64	31/64 × 58/64
4	24/64	27/64	26/64	29/64	215	28/64 × 51/64	30/64 × 54/64
5	23/64	26/64	25/64	27/64	185	26/64 × 48/64	27/64 × 50/64
6	21/64	24/64	23/64	26/64	150	25/64 × 45/64	26/64 × 48/64
8	17/64	20/64	18/64	21/64	100	21/64 × 31/64	22/64 × 39/64
10	15/64	18/64	16/64	19/64	75	19/64 × 33/64	20/64 × 35/64
12	14/64	17/64	15/64	18/64	60	17/64 × 31/64	18/64 × 32/64
14	13/64	16/64	14/64	17/64	45	16/64 × 28/64	17/64 × 29/64
16	10/64	13/64			30	13/64 × 22/64	
18	9/64	12/64			20	12/64 × 21/64	

600 to 3500 Volts

B. & S.	Solid S.B.	Solid D.B.	Stranded S.B.	Stranded D.B.	Wt. per 1000 feet	Duplex Solid	Duplex Stranded
0000	46/64	49/64	51/64	54/64	850	50/64 × 94/64	54/64 × 104/64
000	43/64	46/64	47/64	50/64	700	46/64 × 88/64	50/64 × 96/64
00	39/64	42/64	43/64	46/64	575	43/64 × 81/64	46/64 × 89/64
0	37/64	40/64	40/64	43/64	475	40/64 × 76/64	43/64 × 82/64
1	34/64	37/64	37/64	40/64	375	38/64 × 70/64	40/64 × 77/64
2	32/64	35/64			300	36/64 × 66/64	37/64 × 71/64
3	30/64	33/64	34/64	37/64	260	33/64 × 62/64	35/64 × 67/64
4	28/64	31/64	30/64	33/64	215	32/64 × 59/64	33/64 × 63/64
5	27/64	30/64	32/64	35/64	185	30/64 × 56/64	32/64 × 59/64
6	26/64	29/64	27/64	30/64	150	29/64 × 54/64	30/64 × 56/64
8	23/64	26/64	24/64	27/64	100	27/64 × 49/64	28/64 × 52/64
10	22/64	25/64	22/64	24/64	75	25/64 × 45/64	26/64 × 48/64
12	20/64	23/64	21/64	24/64	60	24/64 × 43/64	24/64 × 44/64
14	19/64	22/64	20/64	23/64	45	23/64 × 41/64	23/64 × 41/64

Weights given are thought to be average weights; duplex wires weigh nearly double the amounts given.

TABLE CXXXI

Approximate Weight and Diameters of Rubber Covered Lead Encased Cables

Single Conductor			0 to 600 Volts — Duplex Conductor	
B. & S.	Diameter	Wt. per 1000 ft.	Diameter	Wt. per 1000 ft.
0000	54/64	1600	54/64 × 104/64	2900
000	51/64	1400	50/64 × 96/64	2600
00	49/64	1250	47/64 × 90/64	2300
0	45/64	1100	44/64 × 78/64	2000
1	38/64	900	39/64 × 68/64	1700
2	34/64	750	38/64 × 62/64	1400
4	29/64	500	32/64 × 56/64	1100
6	26/64	400	28/64 × 50/64	800
8	22/64	300	22/64 × 40/64	600
10	21/64	275	21/64 × 38/64	500
12	18/64	175	19/64 × 34/64	350
14	16/64	150	18/64 × 32/64	300

TABLE CXXXII

8ths.	16ths.	32nds.	64ths.	Mils.	8ths.	16ths.	32nds.	64ths.	Mils.
			1	15.6				33	515.6
		1	2	31.2			17	34	531.2
			3	46.9				35	546.8
	1	2	4	62.5		9	18	36	562.5
			5	78.1				37	578.1
		3	6	93.7			19	38	593.7
			7	109.3				39	609.3
1	2	4	8	125.	5	10	20	40	625.
			9	140.6				41	640.6
		5	10	156.2			21	42	656.2
			11	171.8				43	671.8
	3	6	12	187.5		11	22	44	687.5
			13	203.1				45	703.1
		7	14	218.7			23	46	718.7
			15	234.3				47	734.3
2	4	8	16	250.	6	12	24	48	750.
			17	265.6				49	765.6
		9	18	281.2			25	50	781.2
			19	296.8				51	796.8
	5	10	20	312.5		13	26	52	812.5
			21	328.1				53	828.1
		11	22	343.7			27	54	843.7
			23	359.3				55	859.3
3	6	12	24	375.	7	14	28	56	875.
			25	390.6				57	890.6
		13	26	406.2			29	58	906.2
			27	421.8				59	921.8
	7	14	28	437.5		15	30	60	937.5
			29	453.1				61	953.1
		15	30	468.7			31	62	968.7
			31	484.3				63	984.3
4	8	16	32	500.	8	16	32	64	1000.

CARRYING CAPACITIES OF WIRES FOR SHORT PERIODS AND INTERMITTENT LOADS.

The following tables of carrying capacities were prepared by the use of formulae deduced by the authors from heating curves of a large number of conductors experimentally determined in the laboratories of the Commonwealth Edison Co. of Chicago. The tests were made at the suggestion of the Department of Gas and Electricity of the City of Chicago and in some of these tests the engineers of the above company were assisted by engineers of the city department. A full description of these tests was given in the Electrical World during 1918.

The data used in compiling the figures given were obtainable only in the form of "curves." It is well known that such curves are to a large extent an interpolation of values, and it is therefore quite unlikely that many of the values given would produce exactly the temperature assigned to them if subject to a test. A study of the curves showed that in a general way the temperature rise in any given conductor was proportional to the square of the current used, but there were also some exceptions, due probably to errors of observation and interpolation as well as to a variety of causes.

In order to eliminate these errors as much as possible, and at the same time provide a simple means of

interpolation to determine the carrying capacity of such wires as were not tested, the amperage necessary to bring each size of wire to a certain temperature was first computed. After this had been done, the circular mils of the conductor were divided by the amperage found, thus giving the circular mils per ampere.

The circular mils per ampere of all the conductors tested were then plotted vertically, while the copper contents were laid out horizontally, and the whole combined in the form of a curve in the well known way. The final carrying capacity was then determined by dividing the circular mils in the conductor by the circular mils per ampere indicated by the curve. It is believed that, in this manner, fairly accurate average values have been obtained.

The current which will cause a given temperature rise in a conductor can be found by the following formula:

$$I = xi\sqrt{\frac{T}{t}}$$

in which T is the desired temperature; t the temperature attained in the conductor by the current i and I is the current to be found. This formula does not take into account the fact that the resistance of the conductor increases with the temperature, as this is considered negligible for all practical purposes. The values of t and i are given in the tables for rubber covered wires. Those conductors, in connection with which no temperature rises are given, were not tested, but the current values given were obtained by interpolation as before explained.

The tables applying to conduits also give the dimensions of the conduits used in the tests. Under the heading, "N. E. Code," we give the amperage

allowed by the code. Under the heading, "Calculated Carrying Capacities," we give those calculated as described above. These values must not be used in conflict with the official figures given by the code, as they are not yet sanctioned thereby. The amperages given under, "Short Time in Minutes," are those which it is believed the various conductors can safely carry for the length of time given, provided no appreciable heating has been caused before this load is applied.

Four tables are given. Two of them are calculated for a temperature rise of 72 degrees Fahrenheit, and the other for 36 degrees Fahrenheit. They are also arranged for open and concealed wires, the latter in conduit. The three wires run in conduit were all carrying the same current and the heating effect there obtained will be exceeded only in cases where the four wires of a two-phase system are run in the same pipe. With the ordinary three-wire lighting system, the heating will be considerably less.

The temperature of rubber covered wire should not exceed 120 degrees F. but that covered with other insulations may rise to 150 degrees, and asbestos covered wires may be carried to higher temperatures than this.

The following tables are intended to assist in the selection of the smallest conductor that may be used to carry an intermittent load. The ultimate temperature rise of a conductor subject to an intermittent load depends upon the ratio between the "on" and "off" time of the current. Unless the current is off long enough to allow the loss of the heat accumulated during the "on" time, the temperature will rise.

At low temperatures the dissipation of heat pro-

ceeds slowly, but at higher temperatures it is much more rapid. For this reason, the relative time in which a given quantity of heat can be dissipated varies greatly with the temperature permitted.

A separate table is provided for each size of wire considered; in conduit as well as for open wiring. Each table is divided into two parts. In the left hand portion of the tables is given the time in seconds required for the currents given at the top, under the heading, "Heating Load; Amperes," to raise the temperature of the wire 5 degrees F. within the range of temperature given under the heading, "Temperature Range," in conduit or open wires as the case may be.

Thus, referring to the table for No. 14 wire in conduit, we see that a current of 25 amperes will produce a rise of 5 degrees, between the range of 47 and 52, in 220 seconds, but also that it will require 1,350 seconds to effect a temperature rise from 67 to 72 in the same conductor by the same current. In this connection we need not pay any attention to the lower temperatures, as we are interested only as the critical temperatures are approached.

If an intermittent load is continued long enough, there will be a steady rise in temperature until the point is reached at which the dissipation of heat equals the supply. Therefore, if we allow sufficient cooling time, we can keep the temperature within bounds.

In the right hand portion of the tables we give the time in seconds required to dissipate the heat generated during the time given in the same horizontal lines.

Thus, again referring to the table for No. 14 wire, we see that with a temperature range of 22-27 degrees, the heat produced in 110 seconds requires 300 seconds

to cool off, while if we allow the temperature to go to 57-62, that generated in 400 seconds will be lost in 40 seconds. Cooling times are given with zero load as well as with continued loads of the amperages given.

The temperature of rubber covered wire should not be allowed to rise above 120 degrees Fahrenheit, and that of "Other Insulations" should not go above 150 degrees F. Asbestos covered wires, however, may be allowed to run much hotter. In order to facilitate the selection of the proper conductor there is provided a column "Limiting Outer Temperature." A separate column is provided for rubber covered and other insulation covered wires. The figures there given indicate that, in locations where the temperature of the air does not rise above the values given, the temperature of the conductor may be allowed to rise to the value of the highest figure given in the same horizontal line under the heading "Temperature Range," either in conduit or open wires.

The simplest method of using the tables consists of first determining the limiting outer temperature. Next find the peak number of amperes and the length of time in seconds during which this amperage is used. Then proceed to find the minimum amperage and the length of time during which it is in use. Make notes of these values and always estimate them with a view to obtaining the hardest operating conditions likely to occur. Now proceed to find the smallest wire under which the amperage in question is given and, selecting the horizontal line in which the limiting temperature is found, see whether the ratio of the on and off times corresponding to the temperature given is the same as that in the problem.

Example: We have a peak load of 80 amperes which lasts for 60 seconds and is then reduced to 25 amperes for 200 seconds; this being the estimated regular cycle of operation of the circuit. Wires are in conduit. The smallest wire under which an amperage of 80 or more is found is a No. 8. Here we find, in the horizontal line pertaining to 83 degrees F., that 105 amperes will cause a temperature rise of 5 degrees in 21 seconds and that this heat, even with only 17½ amperes in continued use, requires 285 seconds for its dissipation. This will not do, and we proceed to the next size of wire. Here we find, in the corresponding horizonal line, that 80 amperes will require 100 seconds to raise the temperature of the wire 5 degrees, and that this heat will be lost in 300 seconds, even with 25 amperes in continued use. Furthermore, as the cooling time is three times as long in this case, while in our problem it was three and one-third times as long, the wire thus found will not heat quite as much as indicated and will therefore be safe to use.

Table CXXXII

Wires in Conduit

Table of Carrying Capacities; three conductors in conduit, each carrying same current.

20° C.; 36° F. temperature rise above surrounding air.

Use this table for rubber covered wires in conduit where temperature of air does not exceed 85° F., and for other insulations at temperatures from 85° F. to 125° F.

B. & S. gauge.	Size conduit	N. E. CODE		Calculated Carrying Capacities 36° F. rise				
		Carrying capacity amperes	Temp. rise in deg. F	Indefinite time amperes	Short time in minutes 30	15	10	5
14	½″	15	27.0	17	19	22	24	30
12	¾″	20	31.0	22	24	26	29	35
10	¾″	25	27.9	27	30	35	40	45
8	1 ″	35	29.9	36	43	50	60	65
6	1 ″	50	33.1	52	60	73	80	105
5	...	55	...	56	69	88	100	125
4	1¼″	70	40.7	64	77	97	110	140
3	1¼″	80	34.9	82	93	113	135	165
2	1½″	90	34.7	90	106	130	155	195
1	1½″	100	39.1	96	126	154	180	225
0	2 ″	125	41.2	110	147	182	210	275
2/0	2 ″	150	41.8	130	179	220	260	340
3/0	2 ″	175	39.4	150	213	270	320	420
200000	...	200	...	175	247	310	355	480
4/0	2½″	225	57.6	180	256	325	395	515
250000	...	240	...	205	297	375	455	585
300000	3 ″	275	45.2	238	345	435	535	690
350000	...	300	...	265	395	500	605	790
400000	3 ″	325	42.1	290	440	555	690	850
500000	3 ″	400	48.1	345	529	660	800	1090
600000	...	450	...	390	610	750	915	1225
700000	...	500	...	430	680	830	1025	1400
750000	4 ″	525	44.8	450	710	870	1080	1450
800000	...	550	...	465	745	905	1120	1525
900000	...	600	...	495	810	975	1210	1665
1000000	4½″	650	55.2	525	870	1040	1295	1800

TABLE CXXXIII
WIRES IN CONDUIT

Table of Carrying Capacities; three conductors in conduit, each carrying same current.

40° C.; 72° F. temperature rise above surrounding air.

Use this table for "Other insulations" in conduit where temperature does not exceed 80° F., and for rubber covered wire where temperature of air does not exceed 50° F.

B. & S. gauge.	Size conduit	N. E. CODE		Calculated Carrying Capacities 72° F. rise				
		Carrying capacity amperes	Temp rise in deg. F	Indefinite time amperes	Short time in minutes 30	15	10	5
14	½"	15	27.0	24	26	31	34	42
12	¾"	20	31.0	30	33	37	41	50
10	¾"	25	27.9	38	43	50	55	65
8	1 "	35	29.9	50	60	70	85	95
6	1 "	50	33.1	70	86	105	115	150
5	...	55	...	80	95	125	140	180
4	1¼"	70	40.7	90	110	140	155	200
3	1¼"	80	34.9	110	130	150	190	235
2	1½"	90	34.7	125	150	175	220	275
1	1½"	100	39.1	135	175	215	250	315
0	2 "	125	41.2	140	205	255	290	385
2/0	2 "	150	41.8	185	245	310	360	440
3/0	2 "	175	39.4	215	300	380	430	565
200000	...	200	...	240	350	430	520	675
4/0	2½"	225	57.6	250	360	455	550	720
250000	...	240	...	280	420	525	640	820
300000	3 "	275	45.2	335	485	610	750	965
350000	...	300	...	375	560	700	845	1105
400000	3 "	325	42.1	415	630	775	965	1190
500000	3 "	400	48.1	480	750	925	1130	1520
600000	...	450	...	545	860	1050	1280	1700
700000	...	500	...	600	950	1160	1435	1960
750000	4 "	525	44.8	630	1020	1220	1510	2030
800000	...	550	...	660	1050	1260	1560	2135
900000	...	600	...	700	1140	1365	1690	2330
1000000	4½"	650	55.2	740	1215	1460	1840	2520

Table CXXXIV

Open Wires

Table of Carrying Capacities; open wires.

20° C.; 36° F. temperature rise above surrounding air.

Use this table for rubber covered wires where temperature does not exceed 85° F., and for "Other insulations" where temperature is between 85° F. and 125° F.

B & S. gauge	N. E. Code		Calculated Carrying Capacities 36° F. rise				
	Carrying capacity amperes	Est. temp. rise deg. F.	Indefinite time amperes	Short time in minutes			
				30	15	10	5
14	20	21.6	25	25	29	33	37
12	25	19.1	31	31	39	42	47
10	30	18.0	41	41	47	53	60
8	50	27.9	52	52	60	66	75
6	70	29.5	67	67	80	87	95
5	80	...	80	80	90	100	112
4	90	32.0	90	90	105	120	137
3	100	26.1	100	100	125	145	168
2	125	30.6	120	120	150	175	210
1	150	32.4	140	145	180	220	265
0	200	40.0	160	165	215	260	330
2/0	225	41.2	186	210	250	310	380
3/0	275	45.7	215	250	300	380	465
200000	300	...	240	290	345	440	535
4/0	325	56.0	250	300	360	450	560
250000	350	...	285	335	410	520	660
300000	400	38.0	325	400	475	620	765
350000	450	...	360	450	545	700	895
400000	500	47.0	400	500	600	790	1020
500000	600	51.4	480	600	730	950	1220
600000	680	...	560	690	860	1110	1565
700000	760	...	625	775	970	1260	1785
750000	800	57.0	650	800	1025	1340	1910
800000	840	...	680	850	1090	1400	2040
900000	920	...	730	930	1190	1550	2300
1000000	1000	54.0	775	1000	1285	1665	2500

TABLE CXXXV
OPEN WIRES

Table of Carrying Capacities; open wires.

40° C.; 72° F. temperature rise above surrounding air. Use this table for "Other insulations" where temperature does not exceed 80° F., and for rubber covered wires where temperature does not exceed 50° F.

B & S. gauge	N. E. CODE Carrying capacity amperes	Est. temp. rise deg. F.	Calculated Carrying Capacities 72° F. rise Indefinite time amperes	Short time in minutes 30	15	10	5
14	20	21.6	34	34	40	46	52
12	25	19.1	43	43	54	59	65
10	30	18.0	57	57	67	74	83
8	50	27.9	72	72	84	92	103
6	70	29.5	94	94	109	122	134
5	80	...	110	110	127	141	157
4	90	32.0	125	125	145	165	190
3	100	26.1	145	145	175	202	234
2	125	30.6	168	170	205	245	295
1	150	32.4	195	205	250	309	372
0	200	40.0	225	235	300	360	460
2/0	225	41.2	260	290	350	430	530
3/0	275	45.7	300	345	410	520	645
200000	300	...	335	400	480	610	750
4/0	325	56.0	350	410	500	630	785
250000	350	...	400	470	575	730	925
300000	400	38.0	450	550	660	860	1070
350000	450	...	500	630	760	980	1250
400000	500	47.0	560	700	840	1100	1425
500000	600	51.4	670	840	1025	1330	1785
600000	680	...	780	965	1200	1550	2190
700000	760	...	870	1080	1370	1760	2500
750000	800	57.0	910	1110	1435	1860	2675
800000	840	...	950	1190	1525	1960	2855
900000	920	...	1020	1300	1665	2150	3215
1000000	1000	54.0	1085	1400	1800	2330	3500

Table CXXXVI

Wires in Conduit

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	3 No. 14 Wires in ½″ Conduit Heating load; amperes 15	20	25	45	Cooling Load; Amperes 7½	0
123	93	22-27	2280	250	110	15	300	180
118	88	27-32		300	120	15	210	130
113	83	32-37		450	160	15	195	100
108	78	37-42		660	180	15	125	80
103	73	42-47		1560	210	15	95	70
98	68	47-52			220	15	80	60
93	63	52-57			350	15	60	60
88	58	57-62			400	15	40	40
83	53	62-67			540	15	40	40
78	48	67-72			1350	15	40	40

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	3 No. 12 Wires in ¾″ Conduit Heating load; amperes 20	25	35	60	Cooling Load; Amperes 10	0
123	93	22-27	840	200	50	13	230	200
118	88	27-32		270	50	13	200	150
113	83	32-37		500	60	13	170	100
108	78	37-42		660	80	13	120	100
103	73	42-47		2000	100	13	100	100
98	68	47-52			100	13	100	90
93	63	52-57			120	13	80	80
88	58	57-62			200	13	50	50
83	53	62-67			200	13	50	50
78	48	67-72			220	13	50	50

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	3 No. 10 Wires in ¾″ Conduit Heating load; amperes 25	35	50	75	Cooling Load; Amperes 12½	0
123	93	22-27	1380	210	60	21	360	270
118	88	27-32		210	60	21	250	225
113	83	32-37		270	65	21	200	150
108	78	37-42		300	70	21	150	130
103	73	42-47		540	75	21	90	115
98	68	47-52		1440	80	21	90	85
93	63	52-57			90	21	90	75
88	58	57-62			120	21	90	75
83	53	62-57			140	21	90	75
83	53	62-67			140	21	90	75
78	48	67-72			160	21	90	75

Table CXXXVII

Wires in Conduit

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	3 No. 8 Wires in Conduit Heating load; amperes 35	50	70	105	Cooling Load; Amperes 17½	0
123	93	22-27	1380	210	60	21	510	420
118	88	27-32		240	60	21	345	290
113	83	32-37		270	70	21	285	210
108	78	37-42		350	80	21	240	160
103	73	42-47		540	90	21	180	120
98	68	47-52		900	100	21	120	100
93	63	52-57		1360	105	21	100	100
88	58	57-62			110	21	90	90
83	53	62-67			115	21	90	90
78	48	67-72			120	21	90	90

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	3 No. 6 Wires in Conduit Heating load; amperes 50	70	80	100	150	Cooling Load; Amperes 25	0
123	93	22-27	1000	120	100	45	19	600	330
118	88	27-32	1920	180	100	50	19	420	240
113	83	32-37		200	100	60	19	300	225
108	78	37-42		220	120	80	19	220	200
103	73	42-47		300	140	80	19	180	120
98	68	47-52		360	160	90	19	120	100
93	63	52-57		450	180	90	19	100	100
88	58	57-62		630	220	90	19	100	100
83	53	62-67		840	240	90	19	100	100
78	48	67-72		1260	260	90	19	100	100

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	3 No. 4 Wires in Conduit Heating load; amperes 70	80	90	100	140	210	Cooling Load; Amperes 35	0
123	93	22-27	600	360	240	135	50	22	720	300
118	88	27-32	900	450	270	150	50	22	480	270
113	83	32-37	1260	510	300	160	60	22	480	210
108	78	37-42	2400	630	390	200	70	22	320	150
103	73	42-47		1080	480	240	70	22	220	120
98	68	47-52			600	360	70	22	180	110
93	63	52-57			950	450	75	22	150	90
88	58	57-62			1800	510	75	22	130	80
83	53	62-67				570	75	22	130	60
78	48	67-72				780	80	22	130	60

Table CXXXVIII
Wires in Conduit

Limiting Outer Temp.		Temperature Range in Conduit	3 No. 3 Wires in 1¼″ Conduit Heating load; amperes					Cooling Load; Amperes	
Other Ins.	Rubber Ins.	F.	80	90	100	160	240	40	0
123	93	22-27	780	480	240	60	28	600	420
118	88	27-32	1500	645	300	60	28	400	300
113	83	32-37		900	400	70	28	330	175
108	78	37-42		1300	570	72	28	300	100
103	73	42-47			780	74	28	250	100
98	68	47-52				76	28	240	100
93	63	52-57				80	28	200	75
88	58	57-62				85	28	150	75
83	53	62-67				85	28	150	75
78	48	67-72				85	28	150	75

Limiting Outer Temp.		Temperature Range in Conduit	3 No. 2 Wires in 1½″ Conduit Heating load; amperes				Cooling Load; Amperes	
Other Ins.	Rubber Ins.	F.	90	125	180	270	45	0
123	93	22-27	840	240	65	25	660	480
118	88	27-32	1560	260	70	25	450	350
113	83	32-37		320	75	25	345	240
108	78	37-42		360	85	25	270	200
103	73	42-47		570	95	25	165	150
98	68	47-52		720	95	25	155	110
93	63	52-57		1000	95	25	155	110
88	58	57-62		1900	95	25	155	110
83	53	62-67			100	25	155	110
78	48	67-72			100	25	155	100

Limiting Outer Temp.		Temperature Range in Conduit	3 No. 1 Wires in 1½″ Conduit Heating load; amperes					Cooling Load; Amperes	
Other Ins.	Rubber Ins.	F.	100	125	150	200	300	50	0
123	93	22-27	840	310	170	90	29	750	480
118	88	27-32	1020	330	180	90	29	580	360
113	83	32-37	1560	420	200	100	29	420	300
108	78	37-42		600	220	100	29	360	270
103	73	42-47		810	240	110	29	270	195
98	68	47-52		1000	270	110	29	220	165
93	63	52-57		1560	390	125	29	180	135
88	58	57-62			450	135	29	150	135
83	53	62-67			480	135	29	150	135
78	48	67-72			720	140	29	150	135

Table CXXXIX

Wires in Conduit

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	3 No. 0 Wires in Conduit Heating load; amperes 125	175	250	375	Cooling Load; Amperes 62½	0
123	93	22-27	550	190	85	32	840	525
118	88	27-32	800	210	85	32	600	390
113	83	32-37	1140	230	85	32	480	300
108	78	37-42	2000	250	85	32	420	225
103	73	42-47		300	85	32	350	200
98	68	47-52		400	95	32	300	190
93	63	52-57		480	115	32	270	180
88	58	57-62		540	135	32	190	140
83	53	62-67		700	135	32	190	140
78	48	67-72		1140	135	32	190	140

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	3 No.00 Wires in Conduit Heating load; amperes 150	225	300	450	Cooling Load; Amperes 75	0
123	93	22-27	700	180	60	31	900	500
118	88	27-32	960	190	60	31	720	360
113	83	32-37	1680	210	60	31	570	330
108	78	37-42	4000	220	90	31	435	315
103	73	42-47		230	90	31	360	240
98	68	47-52		250	90	31	250	210
93	63	52-57		265	105	31	195	160
88	58	57-62		285	105	31	160	130
83	53	62-67		315	105	31	160	130
78	48	67-72		400	105	31	160	130

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	3 No. 000 Wires in Conduit Heating load; amperes 175	262½	350	525	Cooling Load; Amperes 87½	0
123	93	22-27	1100	200	100	38	960	540
118	88	27-32	1470	210	100	38	660	480
113	83	32-37	2300	220	100	38	560	450
108	78	37-42		240	110	38	500	350
103	73	42-47		270	110	38	480	310
98	68	47-52		300	110	38	360	270
93	63	52-57		360	120	38	315	180
88	58	57-62		420	135	38	210	120
83	53	62-67		480	135	38	180	120
78	48	67-72		660	135	38	180	120

Table CXL

Wires in Conduit

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	3 No. 200,000 C. M. Cables estimated Heating load; amperes 212	265	318	380	424	636	Cooling Load; Amperes 106	0
123	93	22-27	420	180	135	100	72	29	2040	660
118	88	27-32	495	220	135	100	72	29	1320	540
113	83	32-37	600	240	140	100	72	29	780	450
108	78	37-42	780	250	140	100	72	29	570	300
103	73	42-47	1200	270	150	100	72	29	450	300
98	68	47-52	1980	300	150	100	72	29	390	240
93	63	52-57	3300	340	165	100	72	29	270	180
88	58	57-62		380	165	100	72	29	170	150
83	53	62-67		400	240	100	72	29	170	150
78	48	67-72		480	240	100	72	29	170	150

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	3 No.400 Cables in 2½" Conduit Heating load; amperes 225	281	337	393	450	675	Cooling Load; Amperes 112½	0
123		22-27	420	180	135	100	72	29	2040	660
118		27-32	495	220	135	100	72	29	1320	540
113		32-37	600	240	140	100	72	29	780	450
108		37-42	780	250	140	100	72	29	570	300
103		42-47	1200	270	150	100	72	29	450	300
98		47-52	1980	300	150	100	72	29	390	240
93		52-57	3300	340	165	100	72	29	270	180
88		57-62		380	165	100	72	29	170	150
83		62-67		400	240	100	72	29	170	150
78		67-72		480	240	100	72	29	170	150

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	3 No. 250,000 C. M. Cables estimated Heating load; amperes 250	312	375	437	500	750	Cooling Load; Amperes 125	0
123	93	22-27	420	180	135	100	72	29	2040	660
118	88	27-32	495	220	135	100	72	29	1320	540
113	83	32-37	600	240	140	100	72	29	780	450
108	78	37-42	780	250	140	100	72	29	570	360
103	73	42-47	1200	270	150	100	72	29	450	300
98	68	47-52	1980	300	150	100	72	29	390	240
93	63	52-57	3300	340	165	100	72	29	270	180
88	58	57-62		380	165	100	72	29	170	150
83	53	62-67		400	240	100	72	29	170	150
78	48	67-72		480	240	100	72	29	170	150

Table CXLI

Wires in Conduit

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	3 No. 300,000 C. M. Cables in 3″ Conduit Heating load; amperes					Cooling Load; Amperes	
			275	343	412	550	825	137	0
123	93	22-27	720	360	120	100	33	1140	480
118	88	27-32	840	370	150	100	33	690	400
113	83	32-37	1320	400	160	100	33	600	360
108	78	37-42	1980	420	170	100	33	480	260
103	73	42-47		450	180	100	33	360	240
98	68	47-52		540	190	100	33	300	220
93	63	52-57		810	250	100	33	280	180
88	58	57-62		1080	300	100	33	210	150
83	53	62-67		2040	350	100	33	210	150
78	48	67-72			400	100	33	210	150

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	3 No. 350,000 C. M. Cables in Conduit, estimated Heating load; amperes					Cooling Load; Amperes	
			300	375	450	600	900	150	0
123	93	22-27	840	370	165	105	40	1070	600
118	88	27-32	1000	400	185	105	40	780	485
113	83	32-37	3000	455	200	105	40	660	435
108	78	37-42		480	210	105	40	600	370
103	73	42-47		540	225	105	40	480	320
98	68	47-52		630	240	105	40	400	260
93	63	52-57		825	315	105	40	315	210
88	58	57-62		1080	350	105	40	300	200
83	53	62-67		1900	415	105	40	250	175
78	48	67-72			470	105	40	220	165

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	3 No. 400,000 C. M. Cables in 3″ Conduit Heating load; amperes					Cooling Load; Amperes	
			325	406	487	650	975	162½	0
123	93	22-27	960	390	210	110	46	990	720
118	88	27-32	1170	430	225	110	46	870	570
113	83	32-37	1800	510	235	110	46	720	510
108	78	37-42	4000	540	250	110	46	615	480
103	73	42-47		630	265	110	46	600	400
98	68	47-52		720	290	110	46	510	300
93	63	52-57		840	330	110	46	480	270
88	58	57-62		1080	400	110	46	330	250
83	53	62-67		1740	480	110	46	300	200
78	48	67-72		4000	540	110	46	240	180

Table CXLII

Wires in Conduit

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	3 No. 500,000 C. M. Cables in 3" Conduit Heating load; amperes 400	500	600	700	800	1200	Cooling Load; Amperes 200	0
123	93	22-27	1050	360	250	165	122	42	3500	1080
118	88	27-32	1140	400	270	165	122	42	1620	950
113	83	32-37	1440	430	300	175	122	42	1200	720
108	78	37-42	1860	480	330	175	122	42	900	540
103	73	42-47	2700	560	360	195	122	42	870	450
98	68	47-52		650	390	195	122	42	600	360
93	63	52-57		750	420	210	122	42	500	300
88	58	57-62		870	450	210	122	42	440	240
83	53	62-67		960	465	225	122	42	280	160
78	48	67-72		1260	480	225	122	42	200	110

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	3 No. 600,000 C. M. Cables in Conduit, estimated Heating load; amperes 450	562	675	785	900	1350	Cooling Load; Amperes 230	0
123	93	22-27	1000	420	240	160	122	42	2280	900
118	88	27-32	1110	450	250	160	122	42	1500	720
113	83	32-37	1440	480	260	160	122	42	1150	600
108	78	37-42	2340	580	270	160	122	42	900	500
103	73	42-47	3500	660	290	160	122	42	750	480
98	68	47-52		720	320	160	122	42	660	420
93	63	52-57		780	360	160	122	42	600	390
88	58	57-62		1020	410	160	122	42	510	360
83	53	62-67		1500	420	160	122	42	420	300
78	48	67-72			430	160	122	42	270	250

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	3 No. 700,000 C. M. Cables in Conduit, estimated Heating load; amperes 505	630	757	880	1010	1515	Cooling Load; Amperes 253	0
123	93	22-27	1000	420	240	160	130	45	2280	900
118	88	27-32	1110	450	250	160	130	45	1500	720
113	83	32-37	1440	480	260	160	130	45	1150	600
108	78	37-42	2340	600	270	160	130	45	900	500
103	73	42-47	3500	660	300	160	130	45	750	480
98	68	47-52		720	340	160	130	45	660	420
93	63	52-57		780	380	160	130	45	600	390
88	58	57-62		1020	420	160	130	45	510	360
83	53	62-67		1500	460	160	130	45	420	300
78	48	67-72			500	160	130	45	270	250

TABLE CXLIII

WIRES IN CONDUIT

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	3 No. 750,000 C. M. Cables in 4" Conduit Heating load; amperes 525	656	787	1050	1575	Cooling Load; Amperes 262½	0
123	93	22-27	900	420	230	150	54	2280	900
118	88	27-32	1110	450	240	150	54	1500	720
113	83	32-37	1440	480	250	150	54	1150	600
108	78	37-42	2340	570	270	150	54	900	500
103	73	42-47	3500	660	300	150	54	750	460
98	68	47-52		720	340	150	54	660	420
93	63	52-57		780	370	150	54	600	390
88	58	57-62		1020	410	150	54	510	360
83	53	62-67		1500	450	150	54	420	300
78	48	67-72			500	150	54	270	250

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	3 No. 800,000 C. M. Cables in Conduit, estimated Heating load; amperes 550	688	825	1100	1650	Cooling Load; Amperes 275	0
123	93	22-27	900	420	230	150	54	2280	900
118	88	27-32	1110	450	240	150	54	1500	720
113	83	32-37	1440	480	250	150	54	1150	600
108	78	37-42	2340	570	270	150	54	900	500
103	73	42-47	3500	660	300	150	54	750	460
98	68	47-52		720	340	150	54	660	420
93	63	52-57		780	370	150	54	600	390
88	58	57-62		1020	410	150	54	510	360
83	53	62-67		1500	450	150	54	420	300
78	48	67-72			500	150	54	270	250

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	3 No. 900,000 C. M. Cables in Conduit, estimated Heating load; amperes 600	750	900	1200	1800	Cooling Load; Amperes 300	
123	93	22-27	920	420	250	100	50	2500	930
118	88	27-32	1020	465	260	100	50	1560	780
113	83	32-37	1200	480	270	100	50	1320	720
108	78	37-42	1350	500	280	100	50	1050	660
103	73	42-47	2250	530	290	100	50	870	600
98	68	47-52		550	300	100	50	780	540
93	63	52-57		600	330	100	50	670	485
88	58	57-62		690	345	100	50	600	450
83	53	62-67		960	370	100	50	400	360
78	48	67-72		1400	450	100	50	330	300

Table CXLIV

Wires in Conduit

Limiting Outer Temp. Other Ins.	Rubber Ins.	Temperature Range in Conduit F.	3 No. 1,000,000 C. M. Cables in 4½" Conduit Heating load; amperes 650	812	975	1300	1950	Cooling Load; Amperes 325	0
123	93	22-27	930	420	250	100	50	2500	930
118	88	27-32	1020	465	260	100	50	1560	780
113	83	32-37	1200	480	270	100	50	1320	720
108	78	37-42	1350	500	280	100	50	1050	660
103	73	42-47	2250	530	290	100	50	870	600
98	68	47-52		550	300	100	50	780	540
93	63	52-57		600	330	100	50	670	485
88	58	57-62		690	345	100	50	600	450
83	53	62-67		960	385	100	50	400	360
78	48	67-72		1400	450	100	50	330	300

Table CXLV

Open Wires

Limiting Outer Temp. Other Ins.	Rubber Ins.	Temperature Range of Wire F.	No. 14 D. B. R. C. Wire in Air Heating load; amperes 15	20	25	45	Cooling Load; Amperes 0
123	93	22-27			120	21	21
118	88	27-32			390	21	21
113	83	32-37				21	21
108	78	37-42				21	21
103	73	42-47				21	21
98	68	47-52				21	21
93	63	52-57				21	21
88	58	57-62				21	21
83	53	62-67				21	21
78	48	67-72				21	

Limiting Outer Temp. Other Ins.	Rubber Ins.	Temperature Range of Wire F.	No. 12 D. B. R. C. Wire in Air Heating load; amperes 20	25	35	60	Cooling Load; Amperes 0
123	93	22-27			120	21	24
118	88	27-32			150	21	24
113	83	32-37			660	21	24
108	78	37-42				21	24
103	73	42-47				21	24
98	68	47-52				21	24
93	63	52-57				21	24
88	58	57-62				21	24
83	53	62-67				21	24
78	48	67-72				21	24

Limiting Outer Temp. Other Ins.	Rubber Ins.	Temperature Range of Wire F	No. 10 D. B. R. C. Wire in Air Heating load; amperes 25	35	50	75	Cooling Load; Amperes 0
123	93	22-27		1020	80	32	21
118	88	27-32			90	32	21
113	83	32-37			180	32	21
108	78	37-42			300	32	21
103	73	42-47				32	21
98	68	47-52				32	21
93	63	52-57				32	21
88	58	57-62				32	21
83	53	62-67				32	21
78	48	67-72				32	21

Table CXLVI

Open Wires

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range F.	No. 8 D. B. R. C. Wire in Air Heating load; amperes 35	50	70	105	Cooling Load; Amperes 0
123	93	22-27		960	60	23	40
118	88	27-32			70	23	40
113	83	32-37			85	23	40
108	78	37-42			100	23	40
103	73	42-47			180	23	40
98	68	47-52			1350	23	40
93	63	52-57				23	40
88	58	57-62				23	40
83	53	62-67				23	40
78	48	67-72				23	40

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range F.	No. 6 D. B. R. C. Wire in Air Heating load; amperes 50	70	80	100	Cooling Load; Amperes 0
123	93	22-27		420	150	21	80
118	88	27-32			240	21	70
113	83	32-37			650	21	60
108	78	37-42				21	50
103	73	42-47				21	40
98	68	47-52				21	30
93	63	52-57				21	30
88	58	57-62				21	30
83	53	62-67				21	30
78	48	67-72				21	30

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range F.	No. 4 D. B. R. C. Wire in Air Heating load; amperes 70	80	90	100	140	210	Cooling Load; Amperes 0
123	93	22-27			420	200	60	17	85
118	88	27-32			2000	250	60	17	80
113	83	32-37				600	60	17	75
108	78	37-42					70	17	70
103	73	42-47					80	17	60
98	68	47-52					90	17	50
93	63	52-57					120	17	40
88	58	57-62					160	17	40
83	53	62-67					240	17	40
78	48	67-72					500	17	40

Table CXLVII

Open Wires

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range of Wire F.	No. 3 D. B. R. C. Wire in Air Heating load; amperes 80	90	100	160	240	Cooling Load; Amperes 0
123	93	22-27			1800	70	27	90
118	88	27-32				75	27	80
113	83	32-37				80	27	70
108	78	37-42				85	27	60
103	73	42-47				95	27	50
98	68	47-52				120	27	40
93	63	52-57				180	27	40
88	58	57-62				300	27	40
83	53	62-67				2000	27	40
78	48	67-72					27	40

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range of Wire F.	No. 2 D. B. R. C. Wire in Air Heating load; amperes 90	125	180	270	Cooling Load; Amperes 45	0
123	93	22-27		780	90	32	130	100
118	88	27-32			95	32	90	80
113	83	32-37			100	32	80	60
108	78	37-42			120	32	60	40
103	73	42-47			200	32	52	40
98	68	47-52			330	32	52	40
93	63	52-57			540	32	52	40
88	58	57-62				32	52	40
83	53	62-67				32	52	40
78	48	67-72				32	52	40

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range of Wire F.	No. 1 D. B. R. C. Wire in Air Heating load; amperes 100	125	150	200	300	Cooling Load; Amperes 50	0
123	93	22-27			540	120	41	150	100
118	88	27-32			1300	150	41	100	70
113	83	32-37				200	41	60	60
108	78	37-42				250	41	60	60
103	73	42-47				350	41	60	60
98	68	47-52				500	41	60	60
93	63	52-57				800	41	60	60
88	58	57-62					41	60	60
83	53	62-67					41	60	60
78	48	67-72					41	60	60

Table CXLVIII

Open Wires

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range of Wire F.	No. 0 D. B. R. C. Cable in Air Heating load; amperes				Cooling Load; Amperes	
			125	175	250	375	62½	0
123	93	22-27		2000	100	29	190	72
118	88	27-32			105	29	150	72
113	83	32-37			110	29	110	72
108	78	37-42			115	29	100	72
103	73	42-47			120	29	90	72
98	68	47-52			180	29	80	72
93	63	52-57			300	29	72	60
88	58	57-62			500	29	72	60
83	53	62-67			2000	29	72	60
78	48	67-72				29	72	60

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range of Wire F.	No. 00 D. B. R. C. Cable in Air Heating load; amperes				Cooling Load; Amperes	
			150	225	450	675	75	0
123	93	22-27		375	100	38	250	160
118	88	27-32		500	100	38	210	140
113	83	32-37		750	100	38	190	120
108	78	37-42		1620	120	38	120	110
103	73	42-47			140	38	70	80
98	68	47-52			160	38	60	60
93	63	52-57			180	38	60	60
88	58	57-62			200	38	60	60
83	53	62-67			230	38	60	60
78	48	67-72			260	38	60	60

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range of Wire F.	No. 000 D. B. R. C. Cable in Air Heating load; amperes				Cooling Load; Amperes	
			175	262½	350	525	87½	0
123	93	22-27		390	85	38	120	250
118	88	27-32		465	85	38	120	165
113	83	32-37		690	85	38	120	130
108	78	37-42		2000	100	38	100	120
103	73	42-47			125	38	90	110
98	68	47-52			195	38	80	90
93	63	52-57			300	38	80	80
88	58	57-62			405	38	70	70
83	53	62-67			600	38	70	70
78	48	67-72			930	38	70	70

TABLE CXLIX

OPEN WIRES

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range of Wire F.	No. 200,000 C. M. Wire in Air Heating load; amperes 210	315	420	630	Cooling Load; Amperes 0
123	93	22-27		195	75	29	240
118	88	27-32		195	75	29	200
113	83	32-37		195	75	29	135
108	78	37-42		195	75	29	100
103	73	42-47		240	90	29	80
98	68	47-52		300	105	29	80
93	63	52-57		400	130	29	80
88	58	57-62		540	170	29	80
83	53	62-67		1200	200	29	80
78	48	67-72			250	29	80

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range of Wire F.	No. 0000 C. M. Cable in Air Heating load; amperes 225	337	450	675	Cooling Load; Amperes 0
123	93	22-27	2000	195	75	29	240
118	88	27-32		195	75	29	200
113	83	32-37		195	75	29	135
108	78	37-42		195	75	29	100
103	73	42-47		240	90	29	80
98	68	47-52		300	105	29	80
93	63	52-57		400	130	29	80
88	58	57-62		540	170	29	80
83	53	62-67		1200	200	29	80
78	48	67-72			250	29	80

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range of Wire F.	No. 250,000 C. M. Cable in Air Heating load; amperes 250	375	500	750	Cooling Load; Amperes 0
123	93	22-27		200	100	35	150
118	88	27-32		200	100	35	125
113	83	32-37		220	100	35	110
108	78	37-42		250	100	35	90
103	73	42-47		300	120	35	80
98	68	47-52		400	135	35	70
93	63	52-57		500	160	35	60
88	58	57-62		800	200	35	60
83	53	62-67		1500	300	35	60
78	48	67-72			400	35	60

Table CL

Open Wires

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	No. 300,000 C. M. Cable in Air Heating load; amperes 275	343	412	550	825	Cooling Load; Amperes 137	0
123	93	22-27		1020	285	125	42	240	240
118	88	27-32		4000	480	135	42	210	210
113	83	32-37			750	150	42	150	150
108	78	37-42			2300	160	42	120	120
103	73	42-47				180	42	100	100
98	68	47-52				250	42	90	90
93	63	52-57				275	42	80	80
88	58	57-62				330	42	80	80
83	53	62-67				375	42	80	80
78	48	67-72				600	42	80	80

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	No. 350,000 C. M. Cable in Air Heating load; amperes 300	375	450	600	900	Cooling Load; Amperes 150	0
123	93	22-27		960	300	110	46	360	200
118	88	27-32		3000	450	120	46	240	150
113	83	32-37			720	130	46	180	80
108	78	37-42			1200	165	46	150	80
103	73	42-47				185	46	80	80
98	68	47-52				240	46	80	80
93	63	52-57				290	46	80	80
88	58	57-62				340	46	80	80
83	53	62-67				420	46	80	80
78	48	67-72				500	46	80	80

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	No. 400,000 C. M. Cable in Air Heating load; amperes 325	406	487	650	975	Cooling Load; Amperes 162	0
123	93	22-27		960	300	110	46	360	200
118	88	27-32		3000	450	120	46	240	150
113	83	32-37			720	130	46	180	80
108	78	37-42			1200	165	46	150	80
103	73	42-47				185	46	80	80
98	68	47-52				240	46	80	80
93	63	52-57				290	46	80	80
88	58	57-62				340	46	80	80
83	53	62-67				420	46	80	80
78	48	67-72				500	46	80	80

Table CLI

Open Wires

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	No. 500,000 C. M. Cable in Air Heating load; amperes 400	500	600	700	800	1200	Cooling Load; Amperes	0
123	93	22-27		690	345	190	180	50	480	400
118	88	27-32		1110	480	200	180	50	300	300
113	83	32-37		4000	750	240	180	50	200	250
108	78	37-42			900	270	180	50	125	200
103	73	42-47			1500	300	180	50	84	150
98	68	47-52				360	180	50	84	84
93	63	52-57				540	180	50	84	84
88	58	57-62				750	180	50	84	84
83	53	62-67					180	50	84	84
78	48	67-72					180	50	84	84

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	No. 600,000 C. M. Cable in Air Heating load; amperes 450	560	675	786	900	1350	Cooling Load; Amperes 225	
123	93	22-27		700	360	200	185	52	480	400
118	88	27-32		1200	500	210	185	52	300	300
113	83	32-37			775	250	185	52	200	250
108	78	37-42			950	280	185	52	125	200
103	73	42-47			1600	310	185	52	84	150
98	68	47-52				370	185	52	84	84
93	63	52-57				550	185	52	84	84
88	58	57-62				775	185	52	84	84
83	53	62-67					185	52	84	84
78	48	67-72					185	52	84	84

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	No. 700,000 C. M. Cables in Air Heating load; amperes 500	625	750	1000	1500	Cooling Load; Amperes 262	0
123	93	22-27		660	270	150	53	660	400
118	88	27-32		840	300	160	53	450	300
113	83	32-37		1410	375	170	53	400	250
108	78	37-42			500	180	53	270	220
103	73	42-47			625	195	53	220	200
98	68	47-52			775	210	53	200	200
93	63	52-57			1200	240	53	150	150
88	58	57-62				260	53	150	150
83	53	62-67				280	53	150	150
78	48	67-72				300	53	150	150

Table CLII

Open Wires

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range of Wire F.	No. 750,000 C. M. Cable in Air Heating load; amperes 525	656	787	1050	1575	Cooling Load; Amperes 262	0
123	93	22-27		660	270	150	54	660	400
118	88	27-32		840	300	160	54	450	300
113	83	32-37		1410	375	170	54	400	250
108	78	37-42			500	180	54	270	220
103	73	42-47			625	195	54	220	200
98	68	47-52			775	210	54	200	200
93	63	52-57			1200	240	54	150	150
88	58	57-62				260	54	150	150
83	53	62-67				280	54	150	150
78	48	67-72				300	54	150	150

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range of Wire F.	No. 800,000 C. M. Cable in Air Heating load; amperes 550	687	825	1100	1650	Cooling Load; Amperes 275	0
123	93	22-27		660	270	150	56	660	400
118	88	27-32		840	300	160	56	450	300
113	83	32-37		1410	375	170	56	400	250
108	78	37-42			500	180	56	270	220
103	73	42-47			625	195	56	220	200
98	68	47-52			775	210	56	200	200
93	63	52-57			1200	240	56	150	150
88	58	57-62				260	56	150	150
83	53	62-67				280	56	150	150
78	48	67-72				300	56	150	150

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range of Wire F.	No. 900,000 C. M. Cable in Air Heating load; amperes 600	750	900	1200	1800	Cooling Load; Amperes 300	0
123	93	22-27		720	330	120	58	660	480
118	88	27-32		1035	400	130	58	500	320
113	83	32-37		2400	525	140	58	420	275
108	78	37-42			630	150	58	300	200
103	73	42-47			800	160	58	250	175
98	68	47-52			1100	170	58	200	175
93	63	52-57				180	58	175	175
88	58	57-62				200	58	175	175
83	53	62-67				220	58	175	175
78	48	67-72				250	58	175	175

Table CLIII

Open Wires

Limiting Outer Temp. Other Ins.	Limiting Outer Temp. Rubber Ins.	Temperature Range in Conduit F.	No. 1,000,000 C. M. Cable in Air Heating load; amperes 650	812	975	1300	1950	Cooling Load; Amperes 325	0
123	93	22-27		720	330	120	58	660	480
118	88	27-32		1035	400	130	58	500	320
113	83	32-37		2400	525	140	58	420	275
108	78	37-42			630	150	58	300	200
103	73	42-47			800	160	58	250	175
98	68	47-52			1100	170	58	200	175
93	63	52-57				180	58	175	175
88	58	57-62				200	58	175	175
83	53	62-67				220	58	175	175
78	48	67-72				250	58	175	175

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MODERN
WIRING DIAGRAMS AND DESCRIPTIONS.

CHAPTER I.

CALL BELL CIRCUITS.—BELLS.—DYNAMO CONNECTIONS.

Figure 1 shows a simple bell circuit with extra wires for a door opener to be operated from the vicinity of the bell. In this diagram the wire A may be left out and two ground connections used as shown at E.

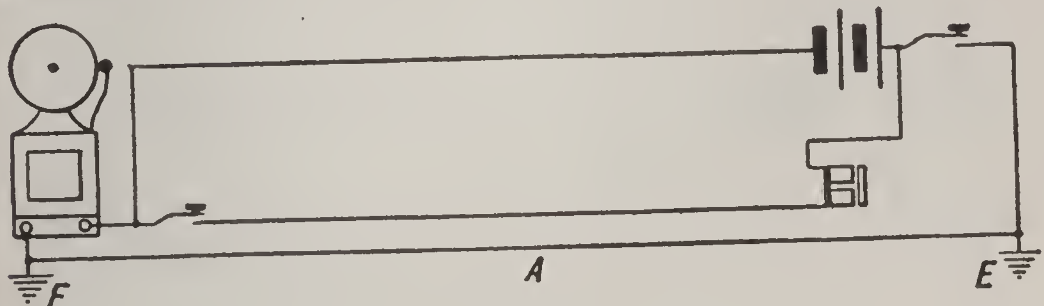


FIGURE 1.

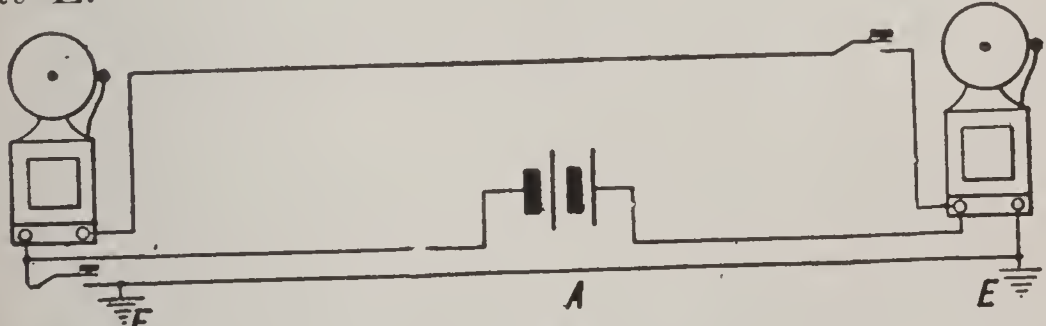


FIGURE 2.

Figure 2 shows a method of wiring usually employed where it is desired that parties at either end

may call and also receive an answering ring as an indication that the signal has been heard.

Figure 3 shows another method of wiring to accomplish the same purpose as the foregoing figure. In this case the bells are in series. This method requires greater battery power and one of the bells must also be arranged to act single stroke.

Two ordinary circuit breaking bells will not act well in series as for instance the one having the stiffer spring or slightly weaker magnet would always lag

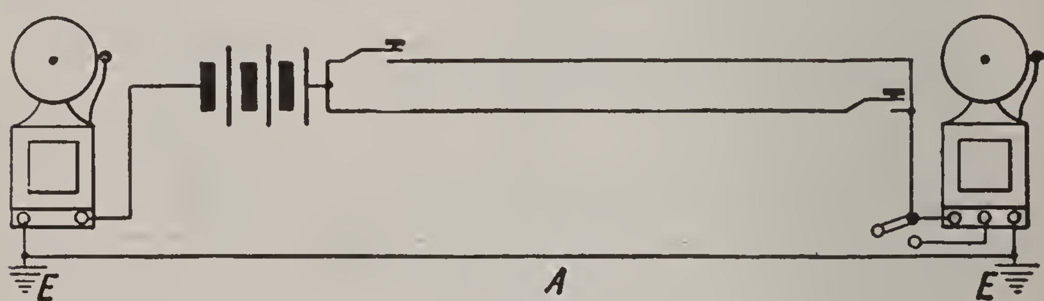


FIGURE 3.

behind the other never coming to a full stroke. The advantage of this arrangement is that it enables the caller to know (by the ringing of his own bell) that the one at the other end is ringing. If the single stroke bell is located at the employer's end and the circuit breaking bell at the attendant's end the employer may know absolutely that the bell at the other end rings when the one at his station does, since it is the attendant's bell which breaks the circuit and causes the one at his own desk to ring. At one station (which may be taken as the attendant's)

there is shown a 3-way switch by which the attendant may change his bell from vibrating to single stroke. This will enable him to arrange so that the bell may attract general attention or that it may be noticed only by one near it.

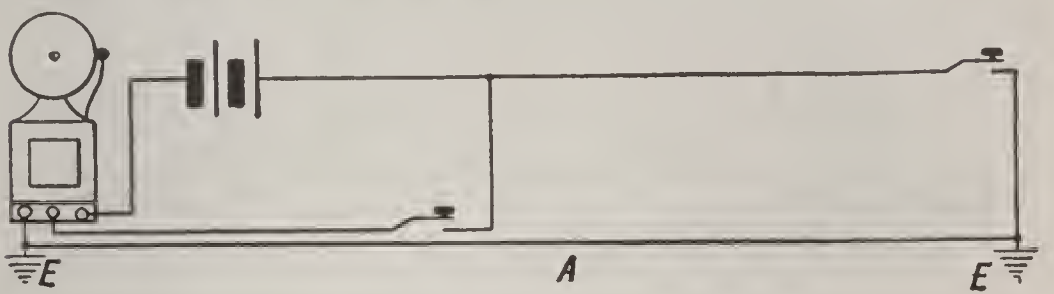


FIGURE 4.

Figure 4 shows one bell arranged to be rung from two stations. From one of the stations it will act single stroke and the ringing will indicate which station is calling.

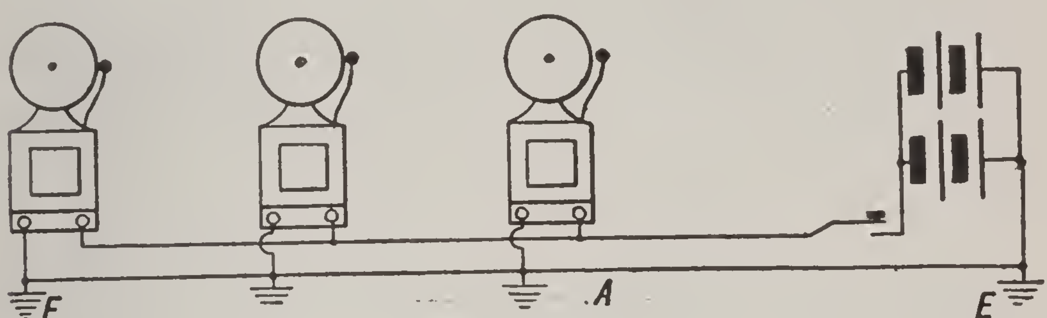


FIGURE 5.

Figure 5 shows a number of bells arranged to be rung from one push button. With this method it is essential that the battery be of low internal resistance and of ample current capacity. This result may be obtained by grouping the cells as shown in the figure; it is, however, preferable to use large cells singly rather than smaller ones in multiple.

Figure 6 shows connections by which either of the right hand pushes will ring the single bell near battery, while from the station at battery the other two bells may be rung with one push button.

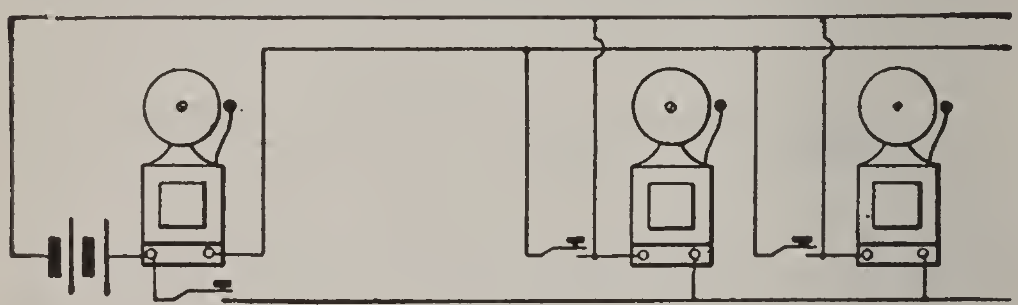


FIGURE 6.

Figure 7 shows two bells arranged with one wire and grounds so that parties at either end may call. This method is economical in regard to wire but requires a battery and 3-way push at each end. The push buttons must normally keep the line closed from bell to bell, leaving the battery circuits open. When a push button is pressed the battery at that end rings the bell at the other.

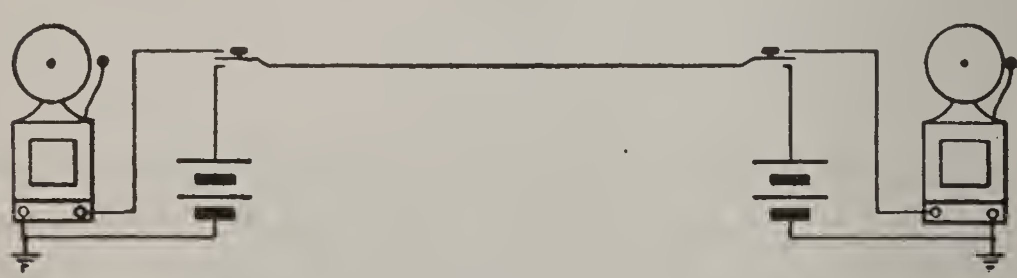


FIGURE 7.

Figure 8 shows a bell so connected that it may be controlled from either of two stations. If both switches are set to the same wire the bell rings. If

either switch is moved to the other wire the bell stops. The advantage of this method lies in the fact that the bell may be left to ring continuously or not as desired. At one station the wiring is arranged

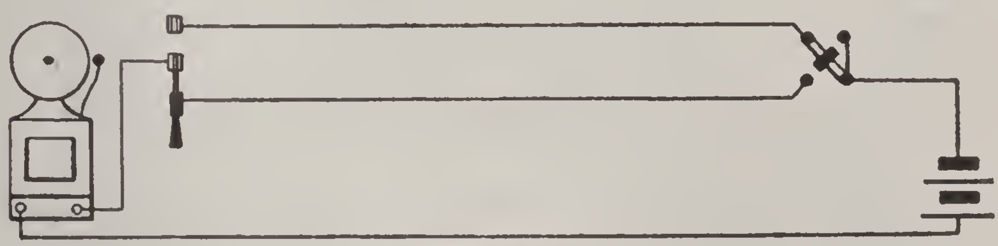


FIGURE 8.

for a double throw knife switch and at the other end for a 3-way snap switch.

Figure 9 shows an arrangement of switches which enables one to turn the bells on or off at any one of any number of stations. These bells are in series and

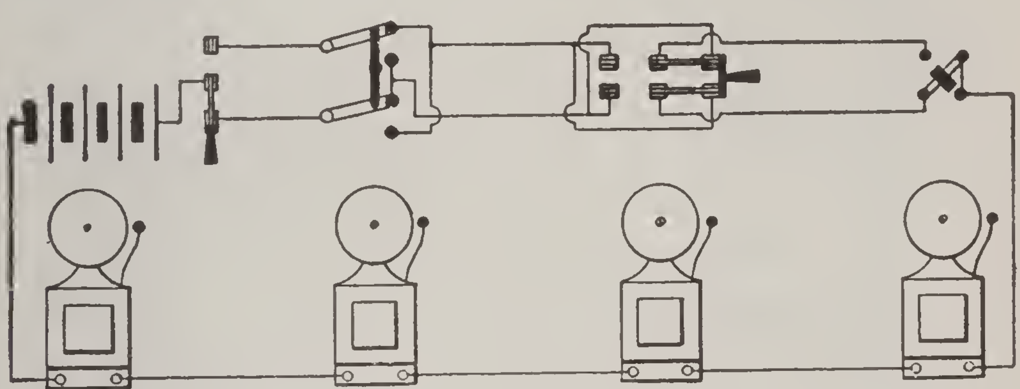


FIGURE 9.

may be left to ring continuously or not as desired. In this diagram throw-over knife switches, snap switches and specially designed switches are shown to illustrate the different ways of attaining the same object.

Figure 10 shows two bells connected by means of the switch S so that either may be used alone or both

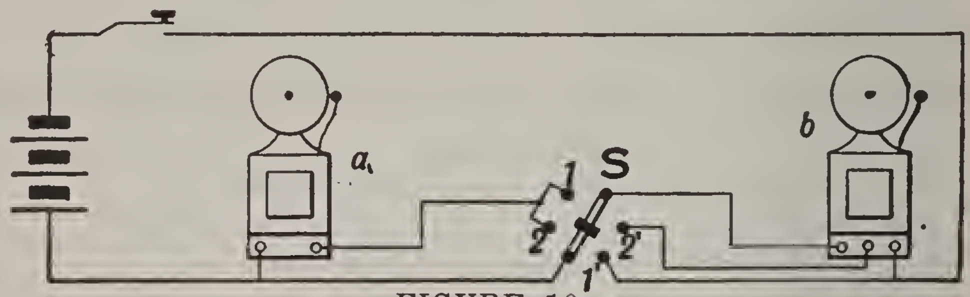


FIGURE 10.

together. With the switch as shown *b* will ring alone. If the switch is turned to 2 and 2′ both bells

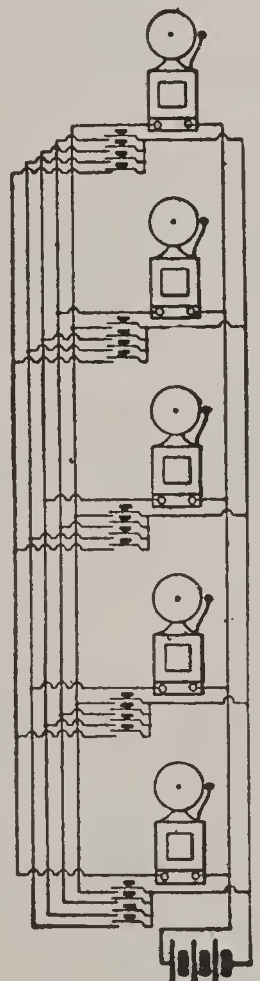


FIGURE 11.

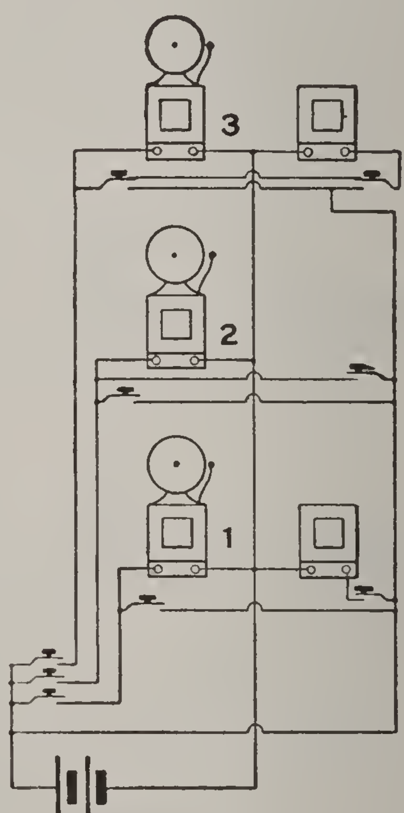


FIGURE 12.

will be in series, one acting single stroke. With the switch connecting 1 and 1′ *a* will ring alone.

Figure 11 shows the manner of wiring commonly used in connection with speaking tube systems. It may also be used with interior telephones. Any station is able to call and may also be called from any other station. Only one battery is used and from one of its poles one wire connects to all of the push buttons. From the other pole another wire passes to one binding post of each bell. From the other binding post of each bell wires are then run to the corresponding push buttons at each of the other stations.

Figure 12 shows an arrangement of wiring often used in connection with flat buildings. One set of push buttons is arranged at the main entrance on first floor usually together with letter boxes and speaking tubes. Another set of push buttons may also be placed one at the front door of each flat. This enables the bell to be rung either from main entrance or from entrance to flat. In addition to these, three different connections are shown in the three flats. In flat 1 a buzzer has been added and is connected to ring from rear door. In flat 2 the same bell rings from main hall, front door and rear entrance. In this case small signs requesting parties to ring a certain number of times will be found very useful at front and rear doors. In flat 3, buzzer and bell will ring from main entrance; the buzzer alone will ring from rear entrance and the bell alone

from front entrance. Three-way pushes are used for front and rear door.

Figure 13 shows the plan of a differential bell. The two coils are wound to oppose one another, so that when current is flowing through both there will be no magnetism. When current is applied at first it flows through one coil only; this attracts the armature, which in turn closes the circuit through the other coil. Both coils now balance, and the armature is released, thus producing the same vibrations as in an ordinary bell.

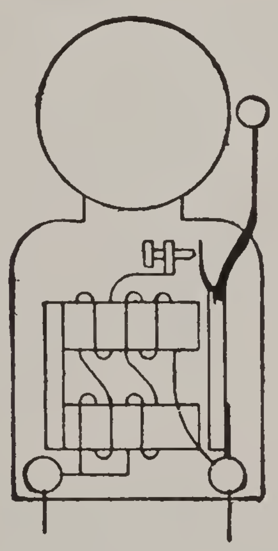


FIGURE 13.

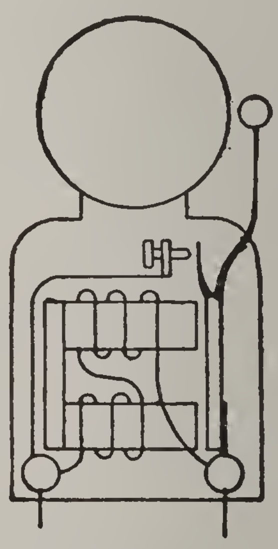


FIGURE 14.

Figure 14 shows a short circuit bell. The current in its circuit is never broken, but, as the magnets attract the armature, the spring in connection with it closes the shunt circuit and this deprives the coil of current, thus destroying its magnetism and releasing its armature. This, and also the differen-

tial bell, will operate with less sparking than an ordinary vibrating bell, and both are useful on circuits of higher voltage. The short-circuit bell should be used only on circuits where other resistances prevent any great rise in current. On an ordinary battery circuit it would not be useful.

Figure 15 shows a bell arranged to act either single stroke or vibrating. For temporary purposes a bell may be made to act single stroke by simply adjusting the vibrator spring so that it does not open the circuit.

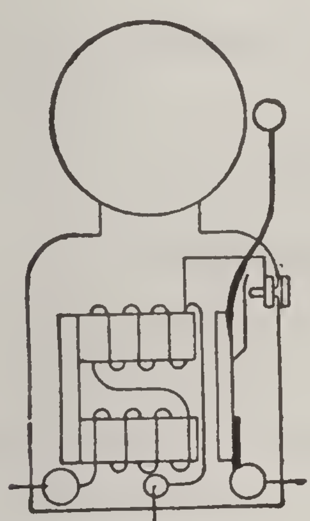


FIGURE 15.

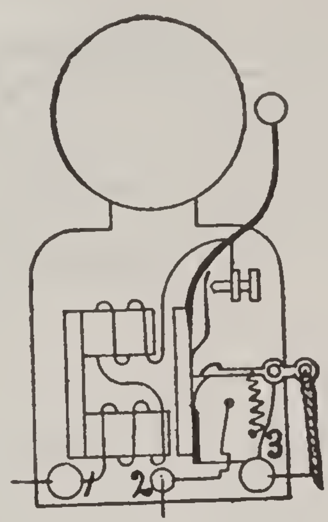


FIGURE 16.

Figure 16 shows a bell with continuous ringing attachment. As the armature is attracted the lever falls and completes the circuit through binding post 2. From this post a wire leads to the battery and completes the circuit through post 1. This attachment may be added to any of the other bells. The

bell will continue to ring until the little lever is placed in its normal position.

Figure 17 shows the arrangement of a polarized bell. This bell may be used in connection with alternating currents, and is the type generally used in telephone work. This type of bell may also be used with continuous currents when provisions for reversing are made; and in this way can be made to act as a single stroke bell, each reversal of current causing one stroke.

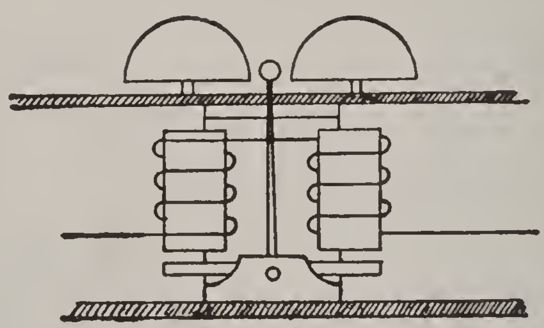


FIGURE 17.

It is often desirable to operate bells from electric light circuits, either direct or through suitable storage batteries. For this purpose incandescent lamps may be placed in series with the bell system, and by choosing lamps of the proper candle power and voltage any necessary current may be obtained. There are also special resistances designed for this purpose which may take the place of lamps shown in diagram or may be placed one with each bell. The main objection to lamps as shown in the diagrams would

be encountered when several bells in a system are to be used at the same time; since only a certain amount of current can pass through the lamps, only one bell at a time can be arranged to work properly. This trouble can be avoided by placing a lamp or resistance in series with each bell and leaving out those shown in diagrams. One lamp on one side of the circuit is sufficient to insure proper operation, but it is advisable to use one on each side, as shown in the figure, to prevent serious damage which might be caused by grounds if one side only contained resistance.

If dynamo current is to be brought into connection with bells, the wiring and insulation should be fully equal to that required for incandescent wiring. Push-buttons should be mounted on fireproof bases and no inflammable material should be used either within or about the bells.

When the ordinary incandescent lamp is used for resistance, it must be borne in mind that the resistance of the lamp when cold is very much greater than when hot or burning; varying in the ordinary 110 volt 16 c. p. lamp from 900 ohms cold to 220 ohms hot. If the lamp is to be used in a circuit where the current is low the cold resistance must be figured, but if the current approaches that at which the lamp burns the hot resistance must be figured, otherwise the rise in current when the lamp heats might damage the instruments in the circuit. To overcome this,

special lamps are made to be used on circuits where the current is low.

In Figure 18 an arrangement is shown by which the battery is automatically disconnected when the

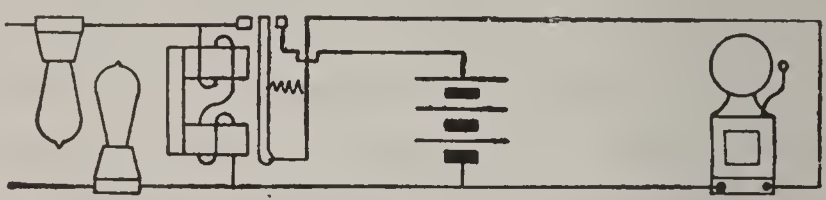


FIGURE 18.

dynamo is in operation. The magnet when energized attracts its armature, thus breaking the battery circuit and completing the dynamo connections to the bell system. When the dynamo current ceases a spring draws the armature back again, closing the battery circuit.

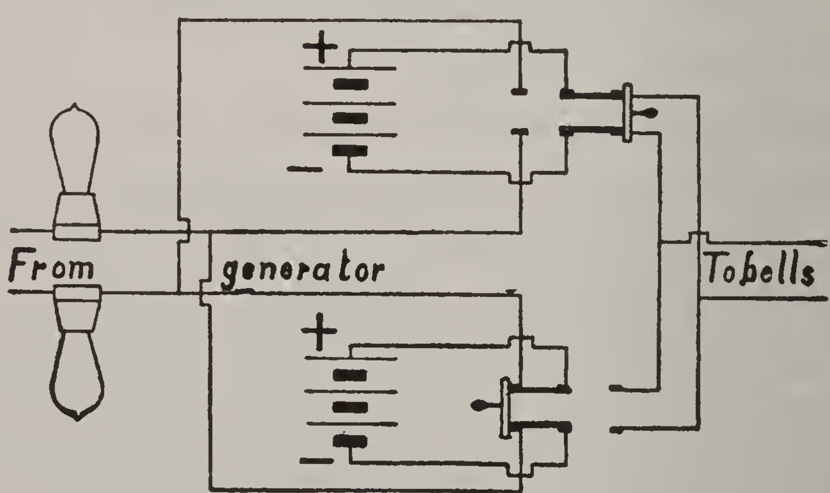


FIGURE 19.

Figure 19 shows two batteries, each provided with a throw-over switch. While one is operating the bells the other is charging. The dynamo current

never comes in contact with the bell wiring and no extra insulation is necessary. The + pole of the dynamo must connect to + pole of battery always, in order to charge.

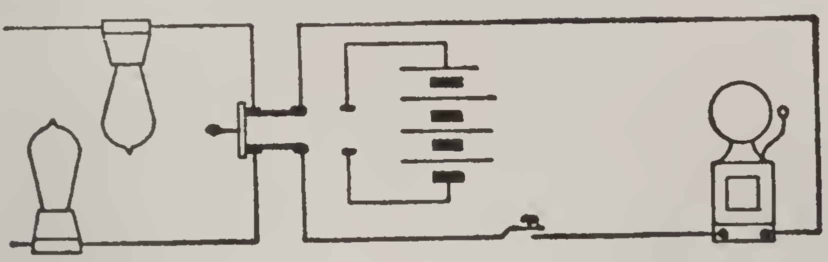


FIGURE 20.

Figure 20 shows dynamo connections direct to the bells and a primary battery provided to operate bells when dynamo is at rest.

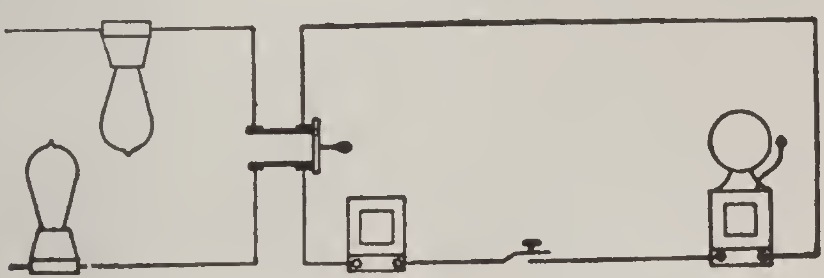


FIGURE 21.

Figure 21 also shows direct dynamo connection to the bell wiring. In this diagram a master circuit breaker in the form of a buzzer or bell is introduced into the circuit, and the bells throughout the building may be arranged single stroke. The sparking is always more destructive with high potential, and often causes much trouble with ordinary cheap bells; therefore this circuit breaker should be of high grade

and located convenient to engineer or janitor, so it may be kept in order. This circuit breaker should also be selected with reference to the bells used, as it must not vibrate faster than the natural vibration of the bells.

CHAPTER II.

ANNUNCIATOR CIRCUITS.

Figures 22, 23 and 24 show diagrammatical representations of ordinary annunciators. In Figure 22 two annunciators are shown, one to be located in the kitchen or hall and the other perhaps in the servant's bedroom. By means of the switches 1, 2, 3, the push buttons are connected to either one of the annunciators as may be desired. The bell connected with each annunciator has a continuous ringing attachment shown by the extra wire attached to the middle bind-

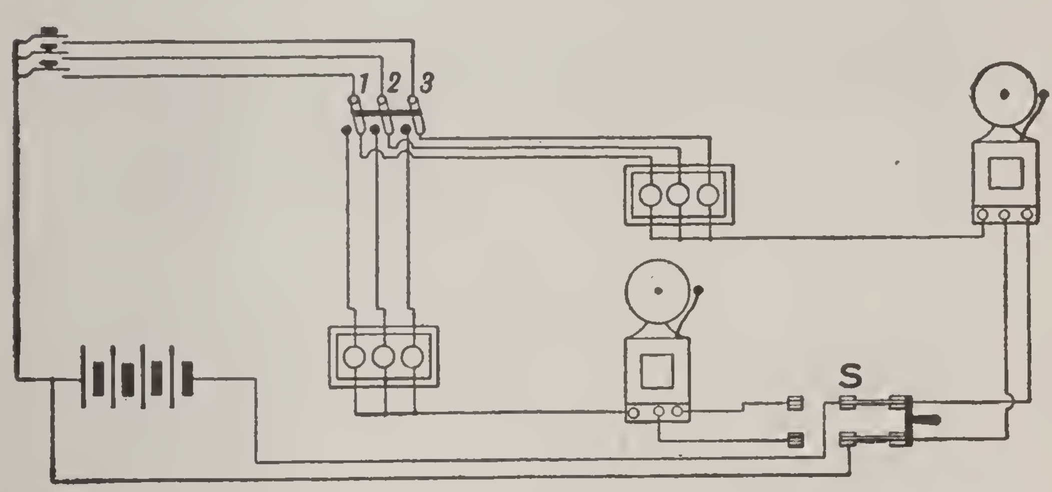


FIGURE 22.

ing post. The overthrow switch S is not absolutely necessary but is quite desirable as a safeguard; it sometimes happens that the continuous ringing at-

tachment falls, and without this switch the bell would ring and run battery down, even though the annunciator were disconnected by the switches 1, 2, 3.

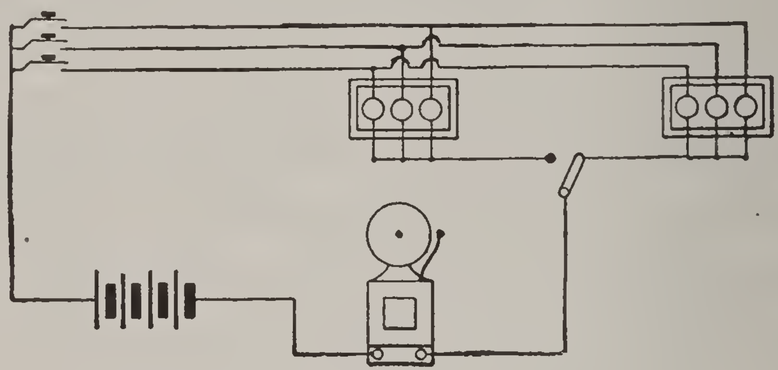


FIGURE 23.

Figure 23 shows a method of connecting two annunciators which should be avoided. With just the right battery strength and accurate adjustment of drops it may work fairly well for a time, but sooner

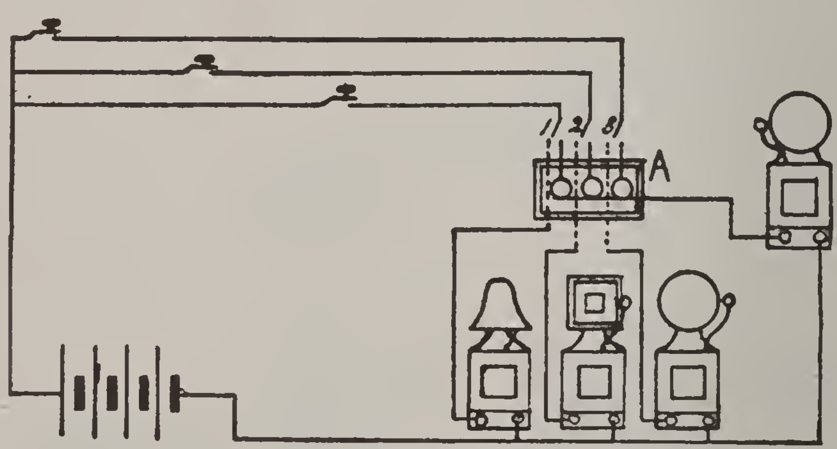


FIGURE 24.

or later it will result in confusion. By tracing out the circuits it will be seen that from any push there are several paths which the current may take although one is more direct and has less resistance than the others.

Figure 24 shows an annunciator to which have been added the switches 1, 2, 3, and also the wires leading to the three bells shown below it. The switches are mechanically connected so that all may be operated at once. These switches serve to disconnect the annunciator magnets and at the same time to connect the three bells with the push buttons. With the switches set to the magnets, the current from any push button passes through the corresponding magnet and through the single bell at the right. With the switches set to the wires leading to the bells the current passes through the corresponding bell without

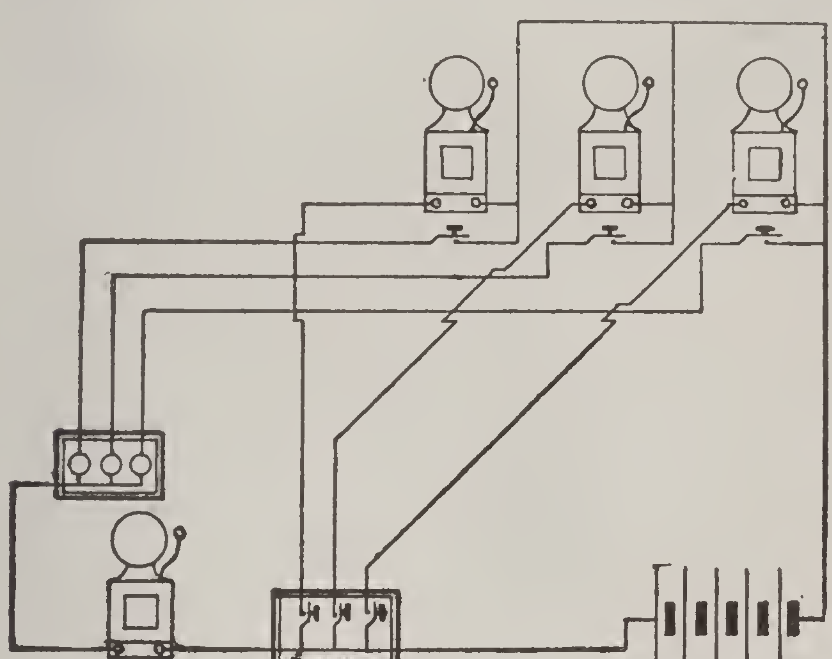


FIGURE 25.

disturbing the single bell. The three bells shown together are of different sound and the ring will indicate location of the caller without the necessity of looking at the annunciator. This may be useful in

many residences where the room in which the annunciator is located is not always occupied.

Figure 25 shows a return call annunciator system as it is frequently used in hotels, where it is necessary that a guest may call the office as well as be called from the office. This system requires one battery and two leading wires for each room, one leading wire passing from each room to the annunciator, while another passes from each push to one of the bells located in rooms.

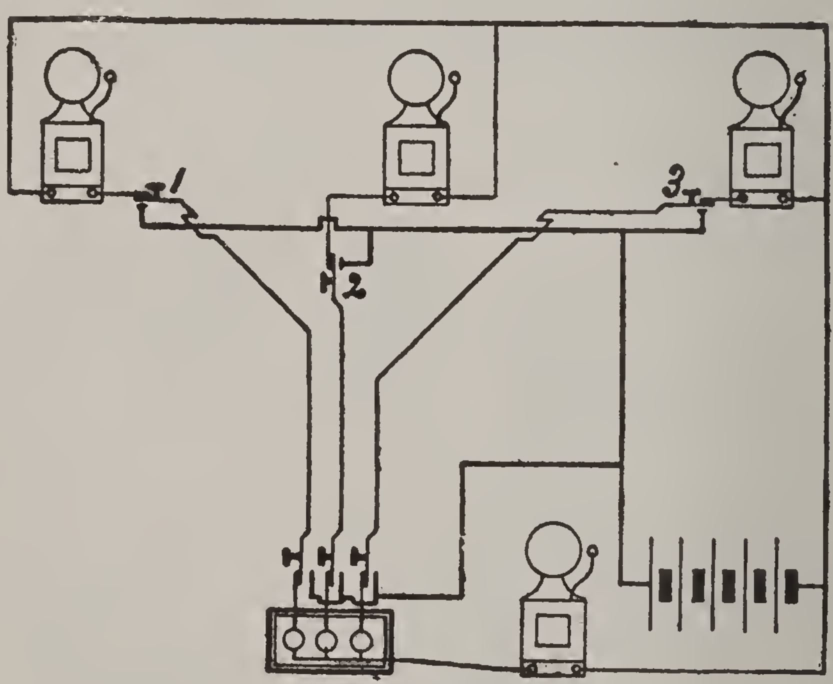


FIGURE 26.

Figure 26 shows another system of annunciator wiring for the same purpose as Figure 25. This system requires only one leading wire from each room, but two general battery wires. One battery wire leads to each bell and to the annunciator, while

the other leads to one point of each push button. Three-way push-buttons are used in the rooms and at the annunciator. Pressing any of the buttons 1, 2, 3, will operate the annunciator, while pressing any of the buttons at the annunciator will ring the bell in the corresponding room.

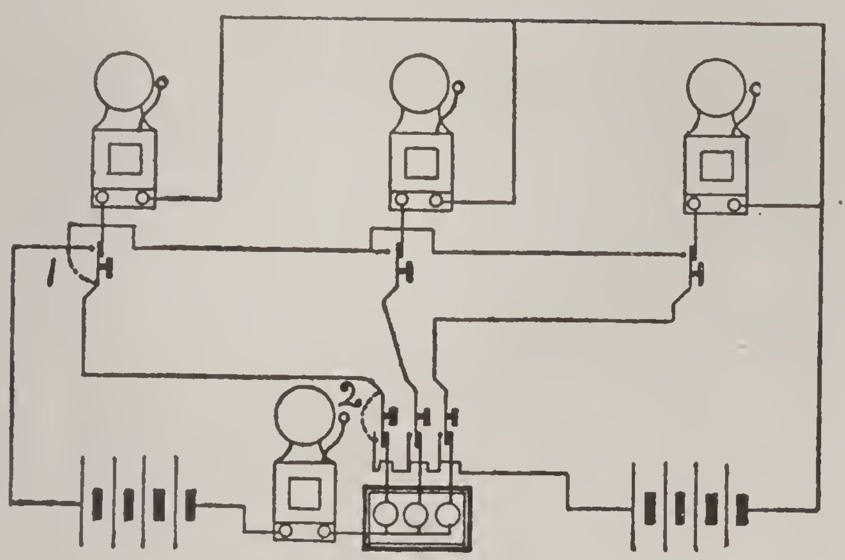


FIGURE 27.

Figure 27 shows diagrammatically the wiring used in the Partrick, Carter & Wilkins annunciator system, which is quite extensively used. Two general battery wires are necessary, and also one wire from each room to the corresponding drop on the annunciator. Two three-way pushes, one at the annunciator and one in each room, are also necessary. These push-buttons are mounted on bells and on annunciator respectively, making the whole arrangement very compact. With reference to each other, the polarities of the two sets of batteries must be as shown. If it were otherwise

both batteries, acting in series, would ring all of the bells and attract all of the annunciator needles whenever the two push-buttons on the same wire were pushed at the same time. This will, however, very seldom occur. By means of the dotted lines at 1 and 2 the circuits thus formed can be readily traced.

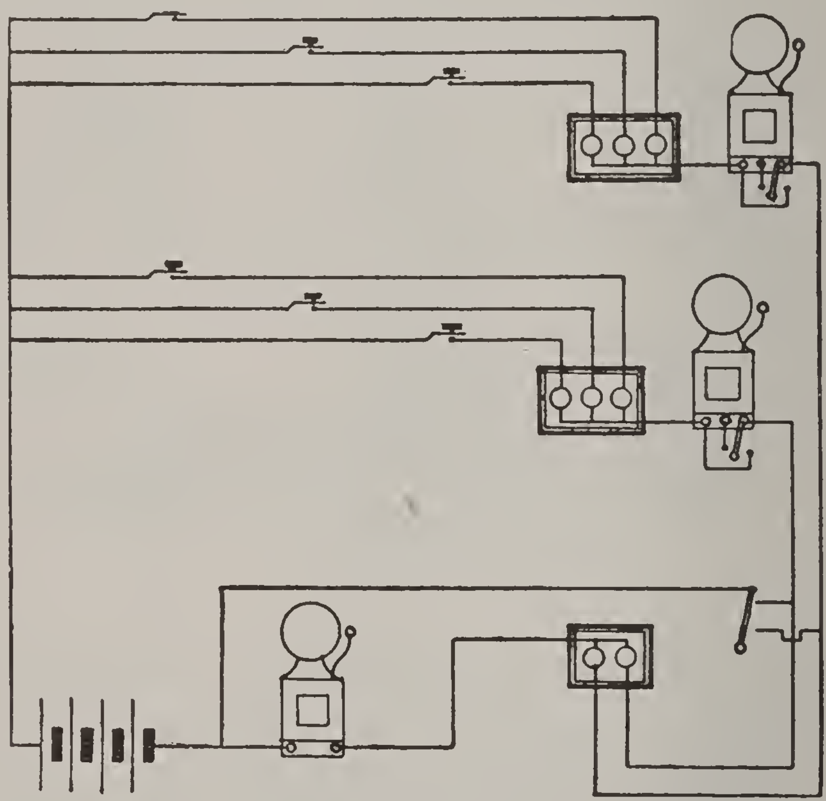


FIGURE 28.

The annunciator magnets used in this system are made so as to partially retain their magnetism after the current ceases to flow, in order to hold the indicator until an attendant releases it. The magnets are magnetized in a certain direction before the annunciator is sent out, and it is advisable to connect the battery so that this magnetism is not reversed.

The binding post on annunciator to which the zinc pole of battery should be connected is plainly indicated on each instrument.

It must not be understood that the P., C. & W. annunciators can be used with this method of wiring only; in fact, either of the methods shown in Figures 25 or 26 are applicable to it, Figure 25 being preferred where it is likely that at some time telephones may be connected with it.

Figure 28 shows an arrangement of annunciators which is quite economical in hotels or restaurants, where there is a great variation in business at different hours. Each floor has an annunciator which indicates the room sending a call, and each of these annunciators is in series with one drop of another annunciator located at the main office and which indicates the floor from which the call came. The bells located with annunciators on the different floors are each provided with a switch, by which any one of them may be made to act single stroke or be cut out altogether. During busy hours an attendant is kept on each floor and the bells are set to act independently, while the annunciator and bells at the main office are cut out altogether by the switch shown. During slack hours the bells on the different floors may be cut out and an attendant stationed at the main office only. The figure shows switches by which the bells may be cut out.

CHAPTER III.

FIRE AND BURGLAR ALARMS.

Figure 29 shows a number of annunciators arranged to act as a manual fire alarm. When any one of the switches S is closed it causes a bell to ring on each floor, and each annunciator indicates from which floor the alarm came. Independent batteries are provided for each floor to insure greater reliability, as one battery failing will disable one floor only. The batteries must all be arranged as shown in diagram, so that all will send current in the same direction.

Figure 30 shows the building system of the Consolidated Fire Alarm Telegraph Company, of New York, and the description here given is condensed from a memorandum furnished by this company to the Underwriters' Bureau of Fire Engineering, and which forms part of Electrical Signal Report No. 14.

The house wiring used with this system consists entirely of two parallel circuits led throughout the building in close proximity. At suitable intervals, as required by the local insurance boards, thermostats, c, and manual switches, D, are installed. The current flows continuously through both circuits, including the magnets A and B. The magnet A while

energized holds at rest a transmitting device which, when released, automatically causes a fire signal to be sent in.

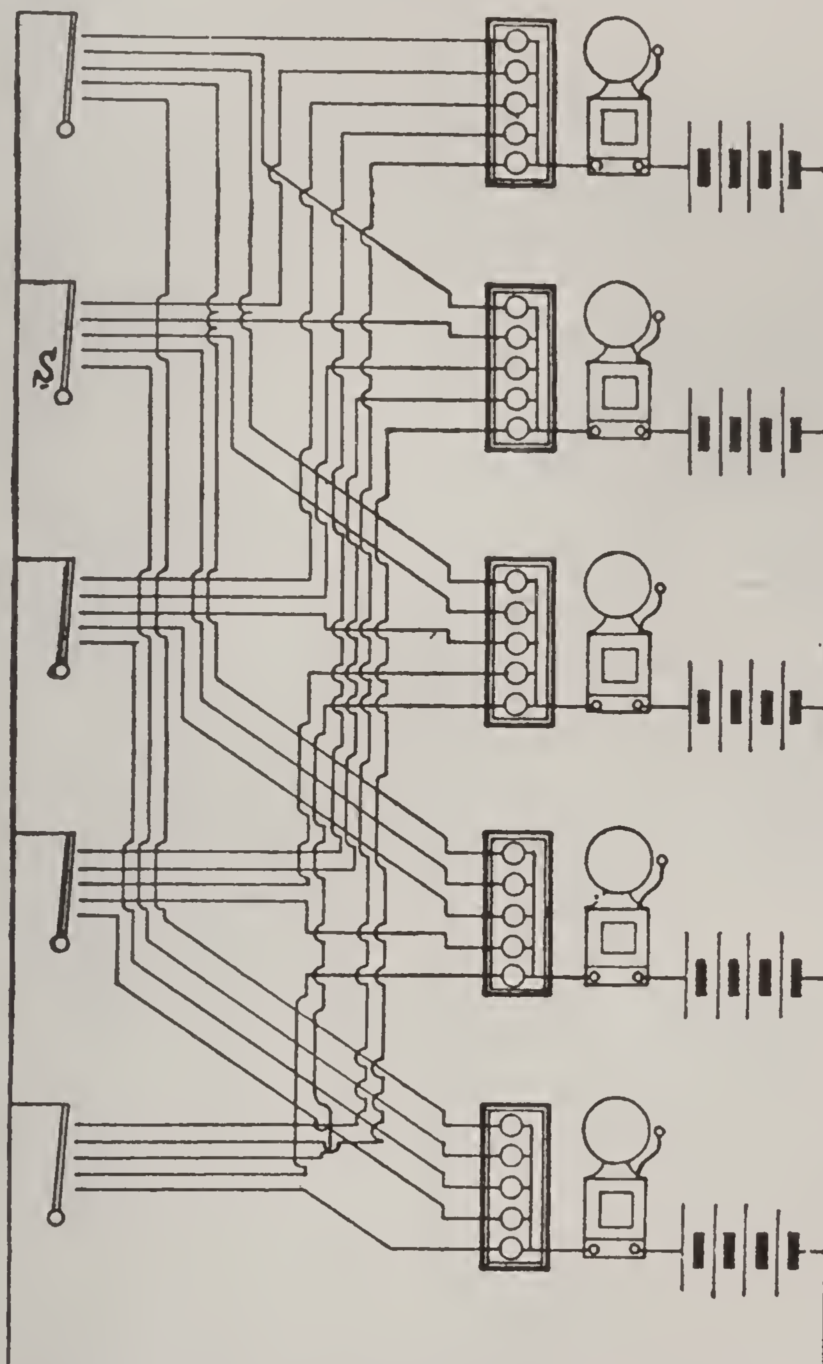


FIGURE 29.

In order to send in a fire signal, it is necessary that both coils of magnet A be de-energized; this will oc-

cur only when both lines are broken, either through the melting of a fuse in each line, or by means of

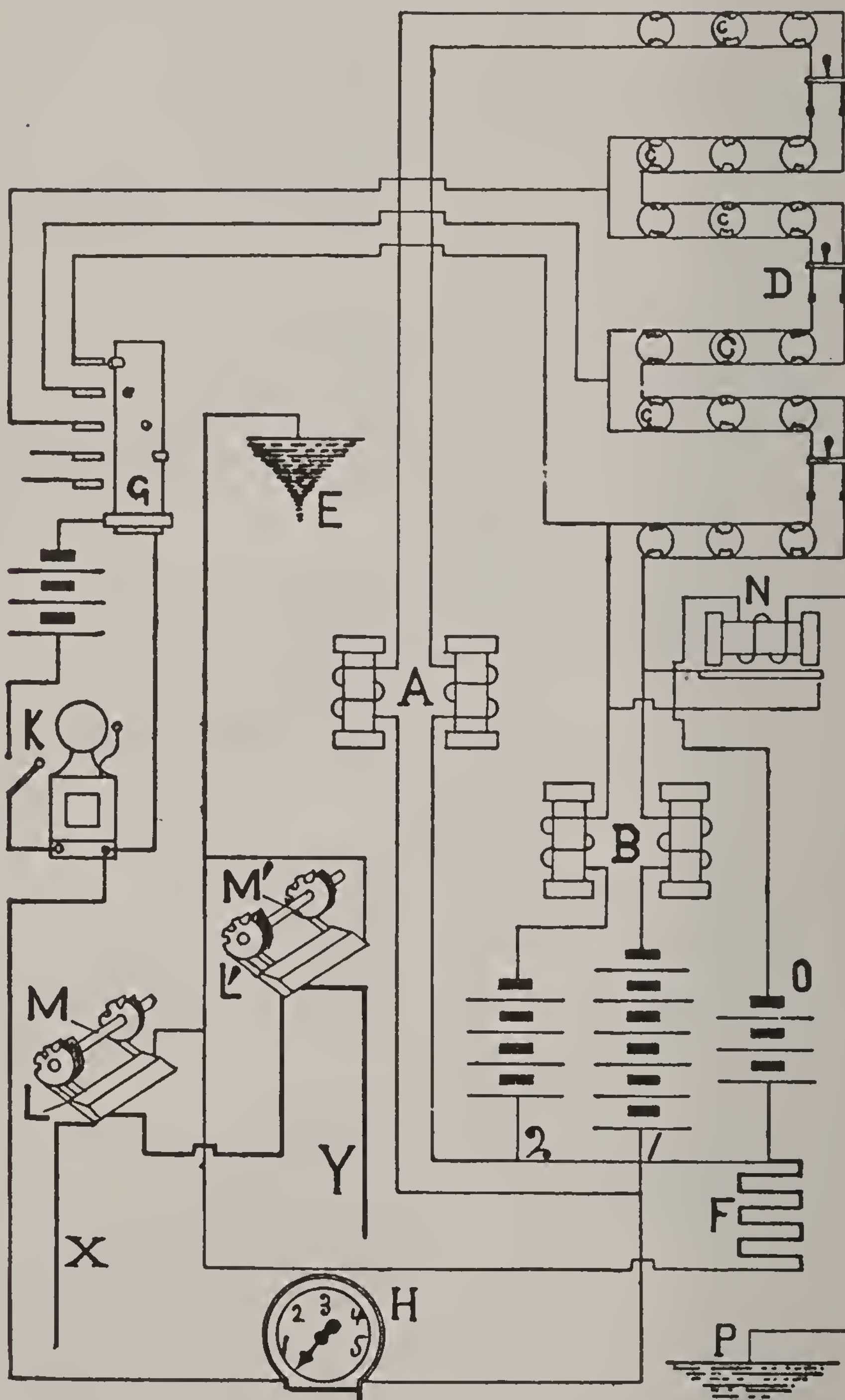


FIGURE 30.

one of the manual switches. The two coils of magnet B are wound in opposite directions, and hence there

is no magnetism while current flows equally in both lines. Should, however, any variation in current strength occur in either of the lines the balance is at once destroyed, and the armature being now attracted releases a transmitting device which sends in a trouble alarm. In order that any possible electrical defect may disturb the balance of the magnet B and send in a trouble alarm, the battery in one of the lines is of higher voltage than the other. The resistance of the magnets and lines vary in the same proportion, so that normally the current in both lines is equal. Part of the transmitting devices are shown at M and M′. The double contact springs L and L′ normally keep the outside circuit X-Y closed. The springs M and M′ are provided to connect the ground E by means of projections on the contact wheels, whenever the double contact springs close on any of the other projections. In this way, by means of the ground, signals are transmitted, even though the circuit X-Y be broken somewhere.

In view of the importance of the grounds E and P, they are placed under constant test by means of the battery O, which maintains current from E to P through the relay N. If this current fails, the armature of N short-circuits the main wires, causing a trouble call to be sent in. Whenever a fire alarm occurs the transmitting device revolves the cylinder G. This cylinder, by means of raised teeth, engages the contact springs of wires led to it from the different

floors, and in this way controls the magnet in the annunciator H, which moves the pointer forward one step for each impulse received. When a point beyond the broken line is reached, the impulses cease and the pointer stops, indicating the location of the fire. The cylinder G is so arranged that the local ringing circuit is closed only when a fire alarm is sent in.

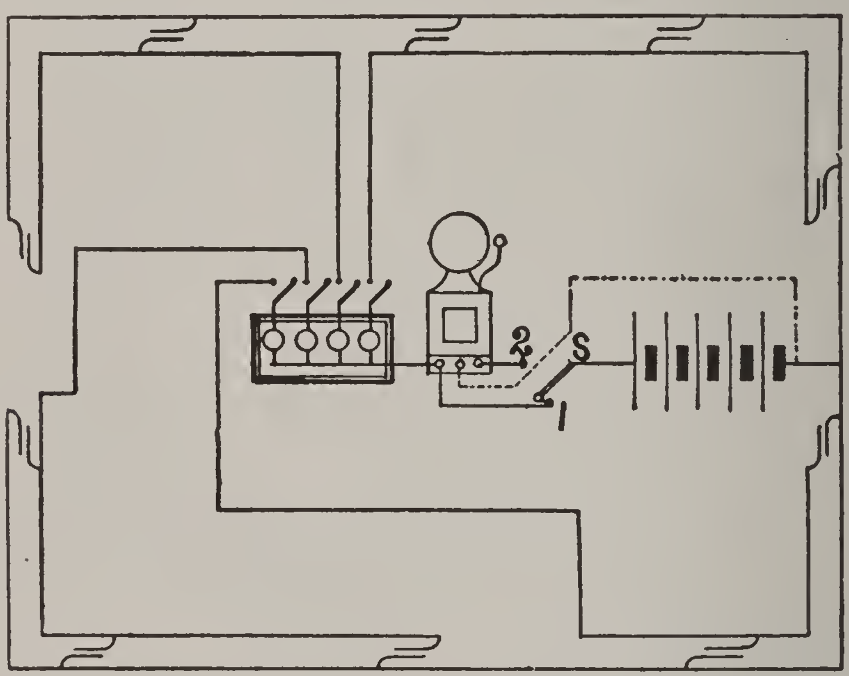


FIGURE 31.

Figure 31 shows an annunciator arranged as a burglar alarm. When used for this purpose it is usual to have the bell arranged to ring continuously when once started. It is also necessary to arrange for what is known as the silent test. For this purpose each circuit leaving the annunciator is provided with a switch by which it may be disconnected during the

day to avoid giving an alarm whenever a door or window is opened. When ready to close the house at night the switch S is turned to connect at 1; each circuit is then thrown in singly, and if any door or window has been left open the drop will indicate it without ringing the bell. When all is in order the switch is turned to 2, thus completing the circuit

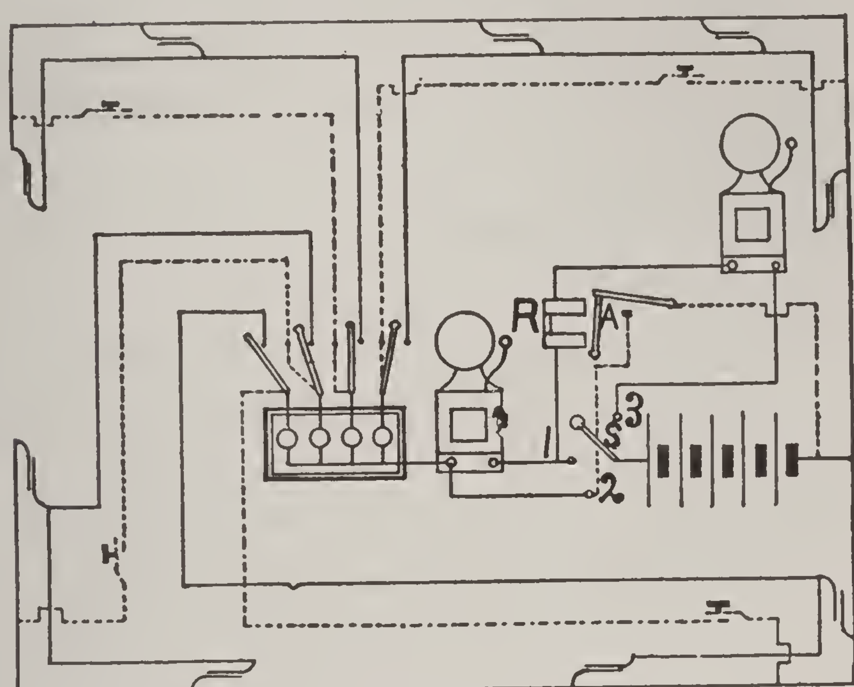


FIGURE 32.

through the bell. The dotted lines show the wiring for the continuous ringing attachment as shown in Figure 16, Chapter I.

With burglar alarm systems it is quite usual to connect the wiring through a suitably arranged clock, which can be made to connect or disconnect the wiring at certain hours. Provision may also be made by which the current, when releasing the annunciator

drop, also releases a weight or spring, allowing them to operate a mechanical bell.

Figure 32 shows the same annunciator and bell arranged to act as a combination burglar alarm and house annunciator. The same provision for silent test has been made as in Figure 31. The solid lines show the wiring for window and door springs, while the dotted lines indicate wiring to push buttons. By means of the four switches shown on the annunciator, the window and door circuits may be shut off during the day, leaving only the push buttons connected. The push buttons are always in circuit, so that an alarm may be turned in at any time.

In this figure an extra bell is shown, which may be connected in series with the annunciator bell by moving the switch S to point 3. In this case the current entering through any drop of the annunciator will pass through both bells and the magnet R to point 3, switch S and the battery. Current passing through R attracts the armature A, allowing the switch to drop, thus closing the battery circuit through both bells, causing them to ring continuously. The extra wiring for this purpose is shown in dotted lines.

Figure 33 shows an attachment for constant ringing which is known as Callows. This consists of a magnet provided with two coils as shown. When the button is pressed current passes around coil 1, and this attracts the armature A, which is also in electrical connection with the battery. A part of the current

now passes along the armature to the wire leading to the bell, and at the junction X it divides, one-half passing through the bell and the other around coil 2 of the magnet. The current passing around coil 2

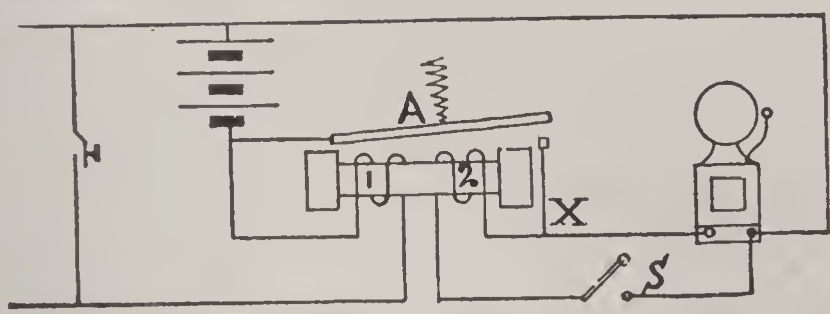


FIGURE 33.

keeps the armature in position while the current in the bell is interrupted. If the switch S is open the bell will ring only while the button is pressed. With this attachment the switch controlling the constant ringing may be at any distance from the bell.

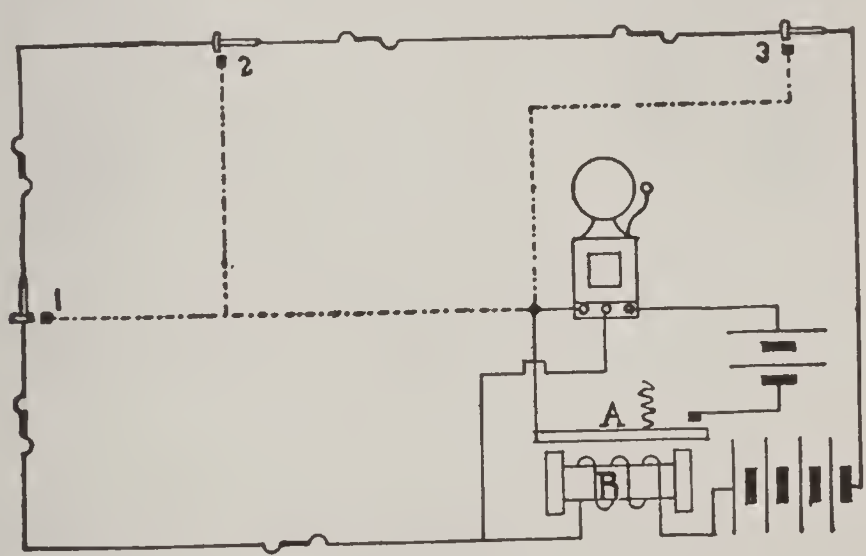


FIGURE 34.

Figure 34 shows a closed circuit burglar alarm. Current is always flowing along the main line. This current, by means of relay R, keeps the local bell cir-

cuit open. Whenever the main circuit is opened anywhere the relay armature A flies back, closing the local circuit and causing the bell to ring. This figure also shows combination wiring, whereby the bell may be used single stroke for calling. Switches are provided at 1, 2 and 3, and arranged so that connection is made with the circuit shown in dotted lines before that in the full lines is broken. While current passes along the wires shown in full lines it passes through the relay only. When one of the buttons makes connection with any of the wires shown in dotted lines, the current passes through the bell and relay. The bell is arranged single stroke for calling, but will ring vibrating when the relay closes the local circuit.

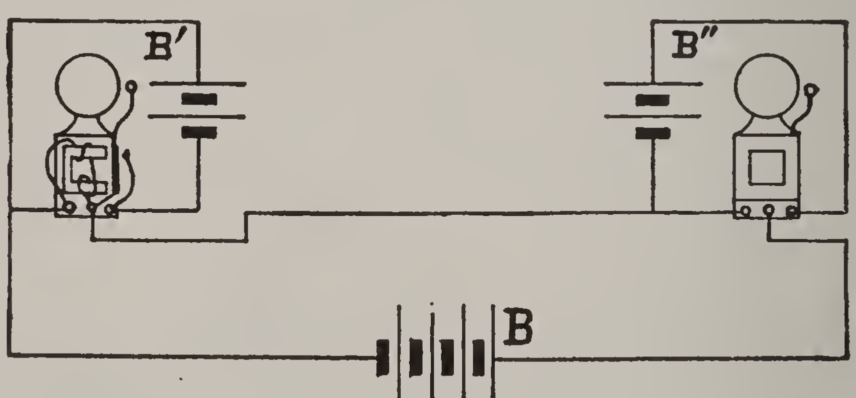


FIGURE 35.

Figure 35 shows a simple closed circuit burglar alarm. In this case the current passes continuously through the bell magnets and keeps the bell armatures attracted. In this way the local circuits B′, B″ are kept open as long as current from the closed cir-

cuit battery B flows through the magnets. Whenever the main wires are opened both bells will ring continuously. Short-circuiting the main wires will also cause one or both bells to ring, according to location of the short circuit. This is a very simple and useful arrangement, and may be extended to any number of bells in a building.

If crow foot batteries are to be used in connection with this system the bells must be specially wound; the ordinary bell has not a sufficient number of turns of wire to operate properly with the small currents obtainable from these batteries.

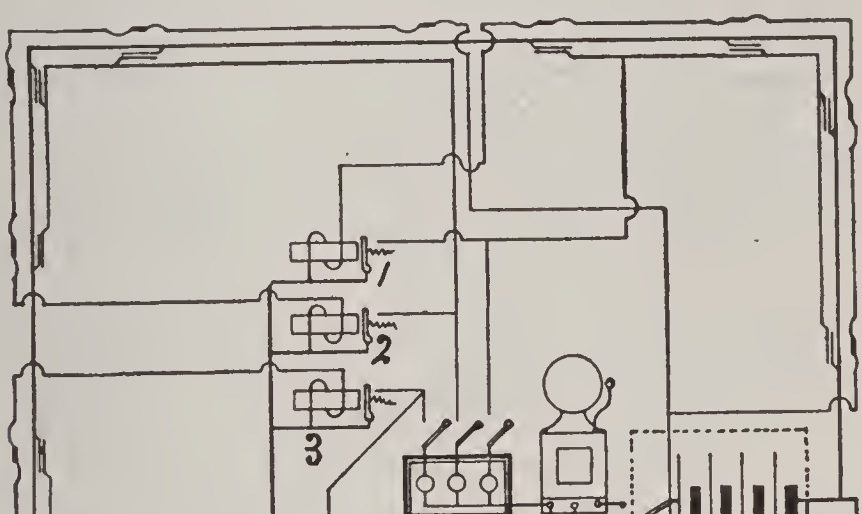


FIGURE 36.

Figure 36 shows a burglar alarm system using both open and closed circuits. Both circuits are run to each opening. The wiring is the same as in Figure

31, and the three closed circuits passing through the three relays, 1, 2, 3, have been added. While current passes through these relays their armatures are attracted; if any circuit is opened the corresponding armature flies back and closes the circuit through the corresponding drop on the annunciator. This system requires a closed circuit battery, and, when certain kinds of cells are used, provision must be made to keep the battery at work if the annunciator is disconnected for any great length of time. As here shown, the battery will always be at work unless a window or door in each section is open.

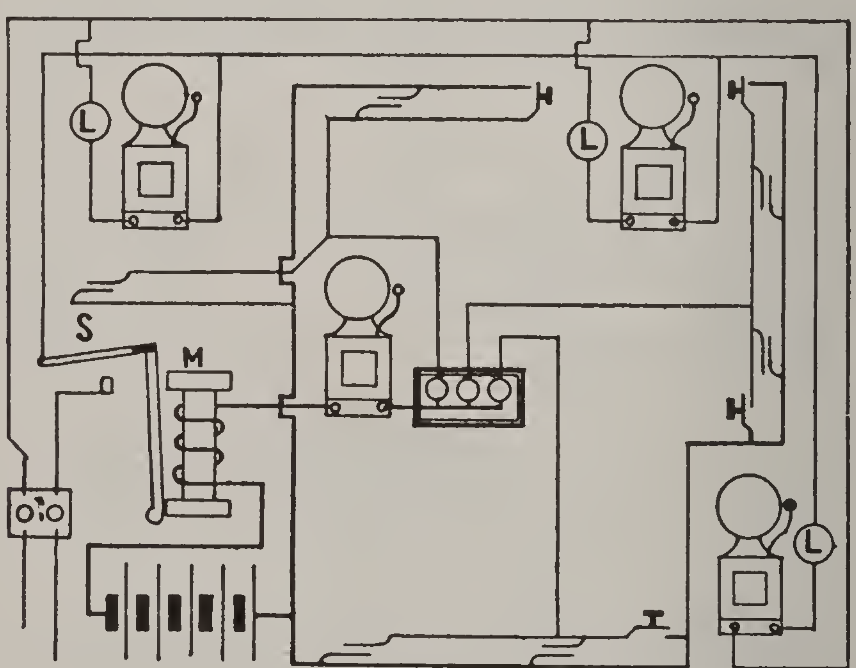


FIGURE 37.

Figure 37 shows an annunciator as it may be used either as a fire or burglar alarm. By means of the magnet M, an electric circuit is closed whenever con-

tact is made by one of the push buttons or contact springs. With each electric light, L, an electric bell is placed, and whenever the alarm is set off bells will ring in the different sections and a general illumination will take place. The bells used for this purpose should be of the type shown in Figures 13 or 14, Chapter I, and should be carefully installed, so there may be no grounding or bad contacts.

The electric light circuit here shown may be added to any of the closed or open circuit burglar alarm systems described by simply arranging a magnet like M, which, by attracting or releasing its armature, allows the switch S to fall and close the electric light circuit. Any burglar alarm annunciator may also be used as a fire alarm if suitable thermostats are connected with the wiring, arranged to open or close the circuit when the temperature rises above a certain point.

Figure 38 shows a system of burglar alarm wiring which can be used when some special object is to be protected. This object may be a safe, vault or room, and may be located any distance from the alarm station.

In the diagram C is a coil of any chosen resistance, which is to be placed inside the object to be protected. By tracing the circuits it will be seen that current from battery B, which is a closed circuit battery, flows through this coil and through a closed circuit

burglar alarm spring G, thence through magnet R′ back to battery.

Another circuit running from the same battery goes through magnets R″ and M, back to battery. When current is flowing from battery B the armature E is held in a balanced position midway between R′ and R″ (this is facilitated by means of springs as shown), and the armature A is attracted. This holds

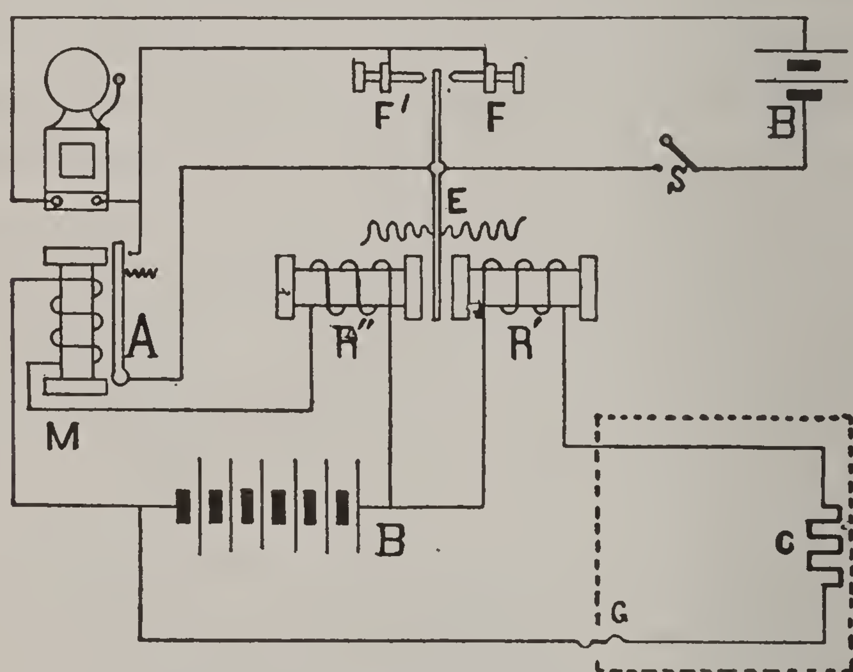


FIGURE 38.

the local bell circuit open. If the line running to C is opened, the current through R′ ceases, and it becomes demagnetized. The armature is then attracted by magnet R″ and the bell circuit is closed at F. If the line running to C is short-circuited, the increased current in R′ attracts the armature and the bell circuit is closed at F′. If for any reason the battery B

gives out, the magnet M is demagnetized and the armature A closes the bell circuit. When alarm is not in use the switch S is thrown over, opening the alarm circuit. This device was designed and patented by G. B. Lehy, of Medford, Mass.

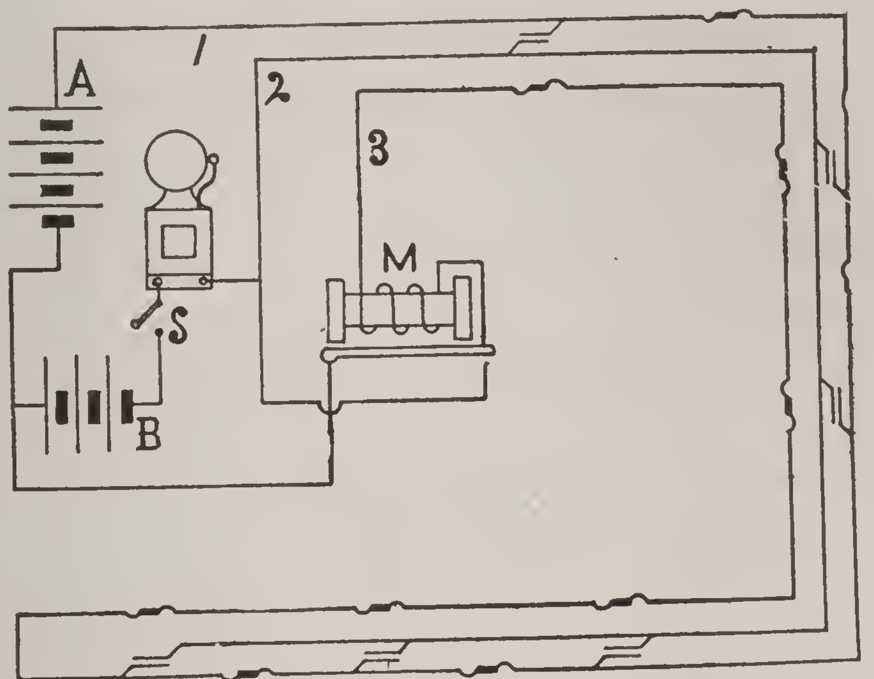


FIGURE 39.

Figure 39 shows the wiring of a burglar alarm in which both closed and open circuits are used. Current from the closed circuit battery A flows continually through wires 1 and 3 and the magnet M. If this circuit is broken the armature of M falls and closes the bell circuit; this rings the bell by means of the open circuit battery B, and keeps it ringing continuously. If any of the springs between 1 and 2 are brought together, both batteries will work through the bell in series.

In systems of this kind the wires may be twisted or braided into cables, and it will be very difficult to determine which wires must be short-circuited or cut in order to make the alarm ineffective. The switch S is provided to cut the alarm bell in or out of use as desired.

This arrangement is taken from Max Linder's book on "Haus Telegraphie," and was devised by O. Schoeppe, of Germany.

CHAPTER IV.

TELEPHONE AND TELEGRAPH CIRCUITS.

Figure 40 shows diagrammatically the connections of an ordinary telephone instrument when in use. While the receiver R hangs on the hook, the line circuit is complete through the polarized bell and magneto generator to ground. This is the connection when the instrument is not in use. T is the transmitter, and it is in series with a small induction coil and

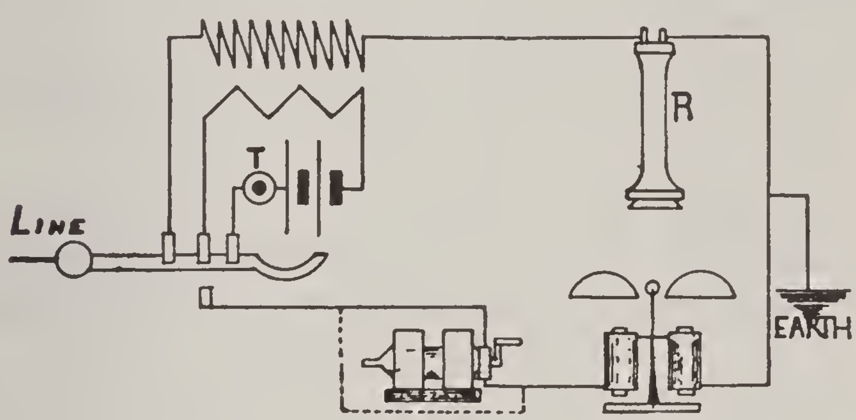


FIGURE 40.

battery, which is connected with the local circuit as shown; the local battery circuit being open when the telephone is not in use. The magneto generator is usually provided with a shunt circuit, which allows the calling currents from other stations to pass around it and ring the bell. The generator is so arranged

that this circuit is automatically opened when the handle is turned.

Figure 41 shows the connections of the bridging bell system. In this system the bells are all in multiple and always in circuit. The resistance of the bell magnets is very high and the self induction quite great. This gives them sufficient impedance to prevent telephonic currents from passing, but does not prevent the lower frequency currents of the magneto from ringing the bells. The magneto generator must be of sufficient capacity to ring all of the bells at the same time. This system requires some code of signals, since all the bells ring whenever any station is called.

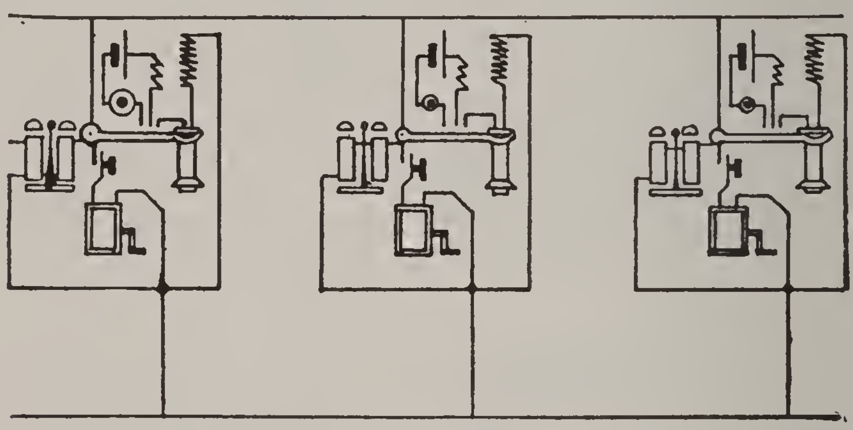


FIGURE 41.

Figure 42 shows a telephone line with the stations arranged in series. With the instruments here shown no induction coil is used, the talking batteries and transmitters being arranged directly in series with the telephone instruments. A signalling battery is re-

quired at each station, and also a 3-way push. Whenever this push is pressed at any station all of the bells will ring. The number of stations that may be ar-

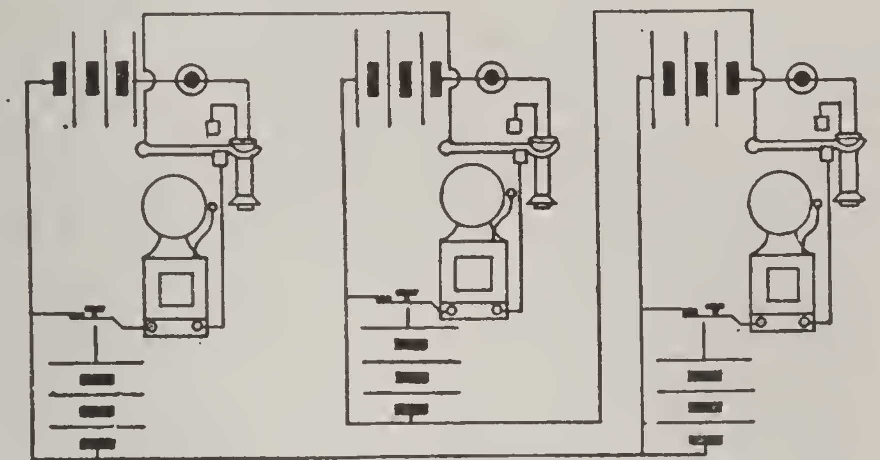


FIGURE 42.

ranged on a line of this kind is very limited, since the talking currents must pass through the bell magnets of all stations except those talking.

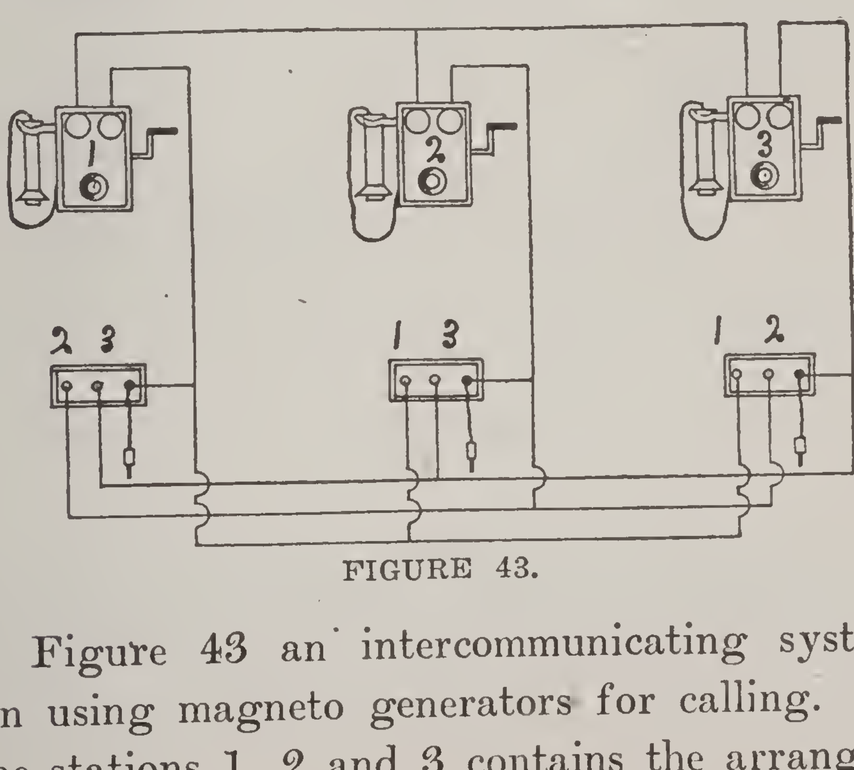


FIGURE 43.

In Figure 43 an intercommunicating system is shown using magneto generators for calling. Each of the stations 1, 2 and 3 contains the arrangement

shown in Figure 40. To call any station the plug is inserted in the jack which connects with the wire leading direct to the station wanted. On turning the generator the bells will ring, and upon taking up the receivers the line is ready for talking.

Figure 44 shows an intercommunicating system using one common battery for signalling and individual talking batteries at each station. As in Figure

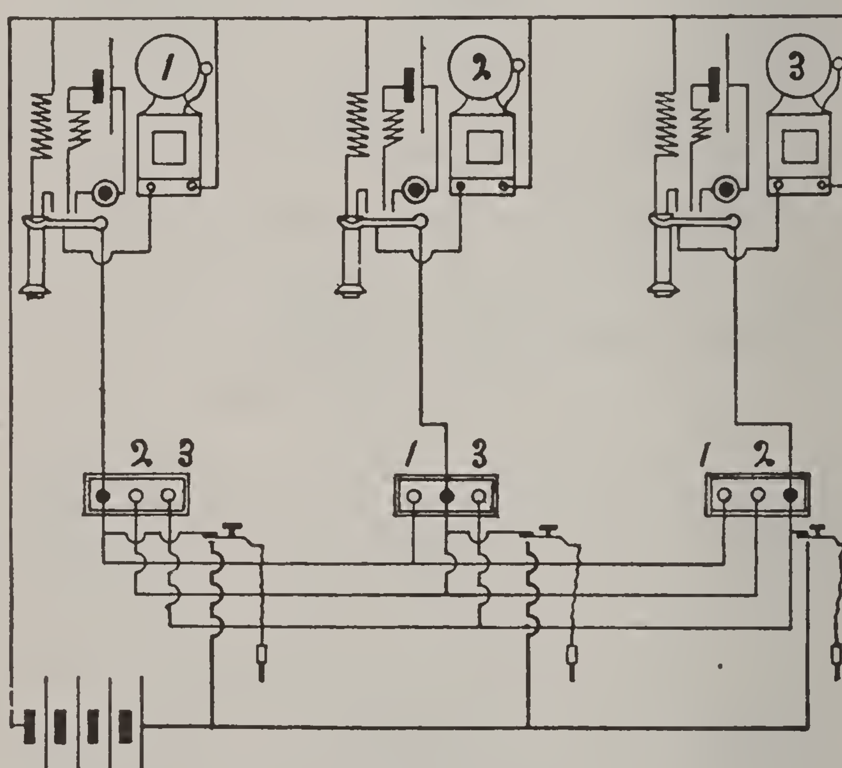


FIGURE 44.

43, the plug is inserted in the proper jack, and upon pressing the 3-way push the bell at the corresponding station will ring. The bell at the calling station will not ring.

With all systems such as these the plugs are likely, through carelessness, to be left in the jacks, and more or less confusion may result. To obviate this, special devices are made, to take the place of plugs shown here, and which automatically make the proper connections when the receiver is replaced.

Figure 45 shows an ordinary annunciator system adapted for the use of telephones. Each station can communicate with the office only. A is the annuncia-

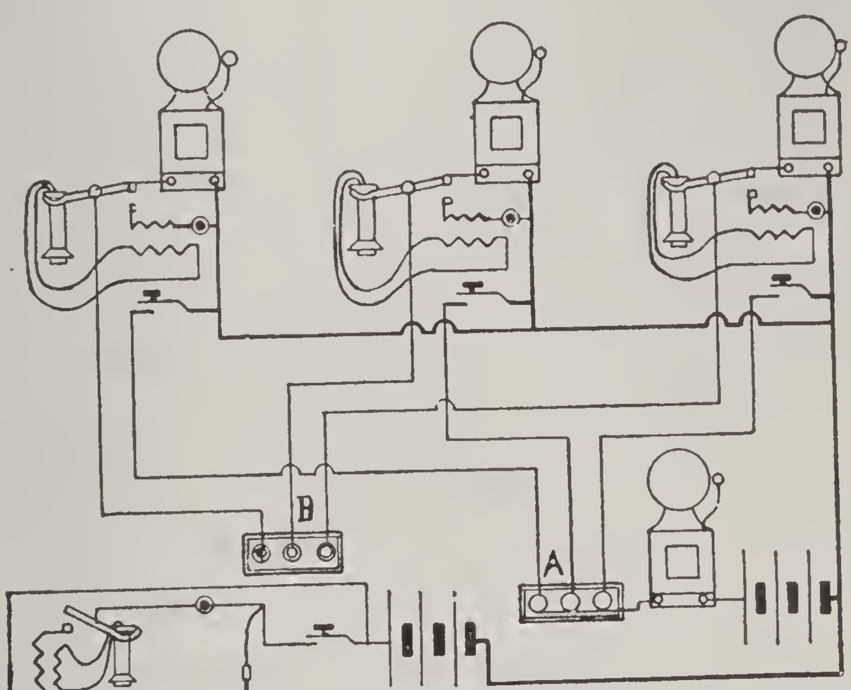


FIGURE 45.

tor receiving the signals from the different stations. By plugging in at the proper wire in B, and pressing the button any station may be called. When the button is released the line is ready for talking if the receivers are removed from their hooks. As here shown,

one common talking battery is used, and another battery is used for signalling.

In Figure 46 an adaptation for telephones of the annunciator system given in Figure 26 is shown. Whenever the plug is inserted in any of the jacks at B, it breaks the wire at this point, thus forming an independent circuit through the station called and the

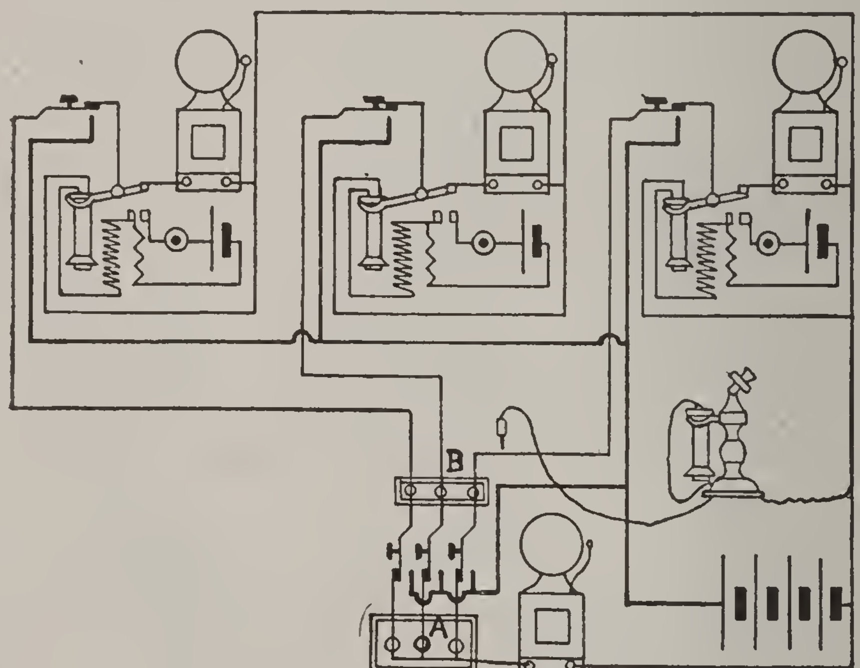


FIGURE 46.

office instrument. With this system there is shown one common signalling battery for all stations and a talking battery at each station.

It has not been thought necessary to give more than the foregoing diagrams in connection with telephones, as anything approaching a full exposition of the many different methods of connecting them would alone fill a volume. The foregoing diagrams

are sufficient to illustrate the methods usually employed in house wiring. For a fuller treatment, and for illustrations of exchange practice, the reader is referred to the more pretentious works dealing with telephone practice only.

As telephone receivers are very sensitive, it is essential that the wires connecting them should not be run very close to other wires carrying currents of electricity. To avoid cross talk and other disturbing influences, the lines should be arranged so that both sides are of equal length and resistance. Arrangements should be such that no electro-magnets are left in circuit when the line is used for talking. It is also advisable to cross wires or twist them together; this will help neutralize inductive influences. In factories and kindred places where there is much vibration, the telephone instruments may be suspended from springs.

Figure 47 shows the connections of an ordinary long distance telegraph line with relays R and sounders S. The relays are used, because in long distance lines it has been found unprofitable to maintain currents sufficiently strong to control the heavy armatures necessary on sounders to make the signals audible. For this reason the relays are equipped with very light armatures, and control a local circuit which operates the sounder. One-half the battery is placed at each end of the line; this lessens the trouble from leakage. Each station is also equipped with a light-

ning arrester connected to ground, as shown, and a switch closing around the key. This applies to intermediate stations as well as end stations, and intermediate stations are also equipped with a switch, by

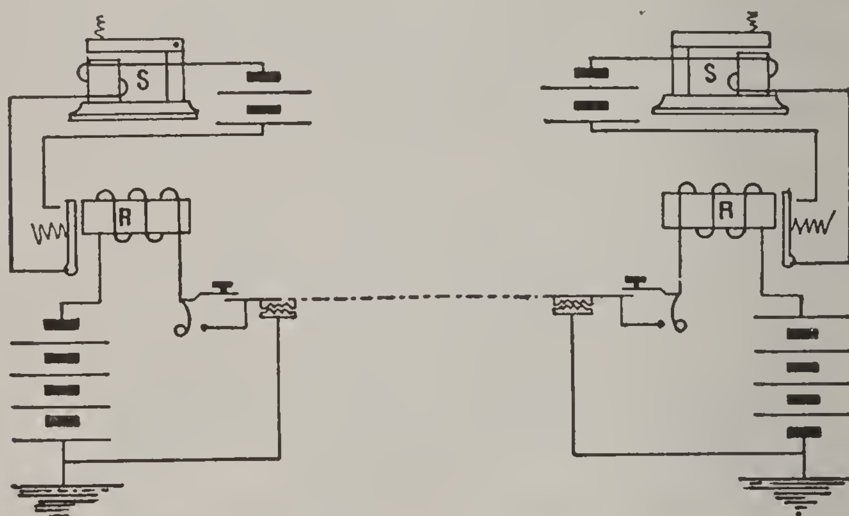


FIGURE 47.

which they may be entirely cut out or connected to ground on either side, in case of a broken line or other trouble.

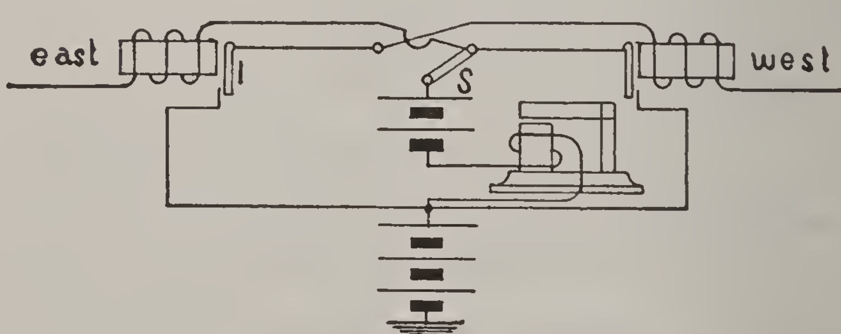


FIGURE 48.

In Figure 48 a very simple form of repeater is shown, which is due to Edison. It can be very readily set up, and requires no additional apparatus except

a 3-way switch shown in diagram. With the switch S, as shown, the current from the eastern line passes through both batteries to ground and keeps the armature I attracted. At the same time current from the west passes through the armature I and the main battery to ground. When the eastern circuit is opened, armature I is released and opens the western circuit, thus repeating into it. With the switch turned to the other point, the western circuit will repeat into the eastern.

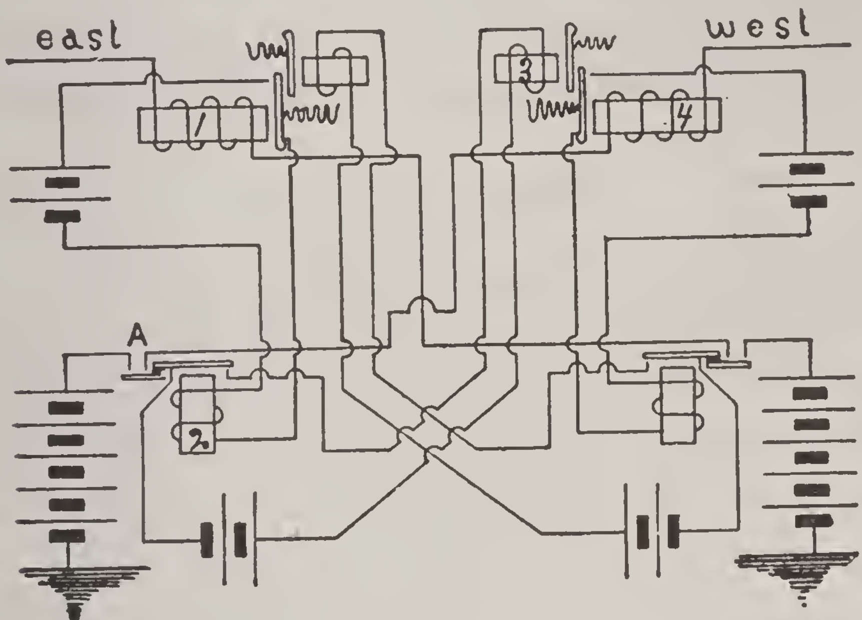


FIGURE 49.

In Figure 49 another form of repeater, known as Milliken's, is shown. This does not require the changing of any switch to make one circuit repeat into the other, but is entirely automatic. The current coming from the east normally keeps the armature of magnet 1 attracted; this armature controls the

circuit of magnet 2. If, now, the current in the eastern circuit is interrupted, the armature of 1 flies back, opening the local circuit of magnet 2; this in turn releases its armature and breaks the western circuit at A. The breaking of this circuit would result in releasing the armature of 4, but at the same instant the armature of 2 opens the western circuit it also opens the extra circuit controlling the magnet 3. This releases the pendant armature, which is drawn by its spring against the armature of 4 and prevents its opening the circuit. The west end station is an exact duplicate of the eastern, and when sending from that side the operation is repeated in a similar manner.

THE TELAUTOGRAPH.

An elementary diagram of the connections of the telautograph is given in Figure 49a and the complete connections showing switches, etc., in Figure 49b.

The message to be transmitted is written upon the platen P, Figure 49b, by a pencil occupying the position shown as a black dot. The movement of the pencil, by means of light rods, moves the arms A, A′, sometimes pulling one and pushing the other. These arms move over resistances and thereby vary the current strength in two lines which lead to the receiver shown in upper half of the figure. In the receiver each of the two magnets M, M′, are fitted with plungers which are free to move up and down. These plungers are drawn upward by springs and sucked into the cores of the mag-

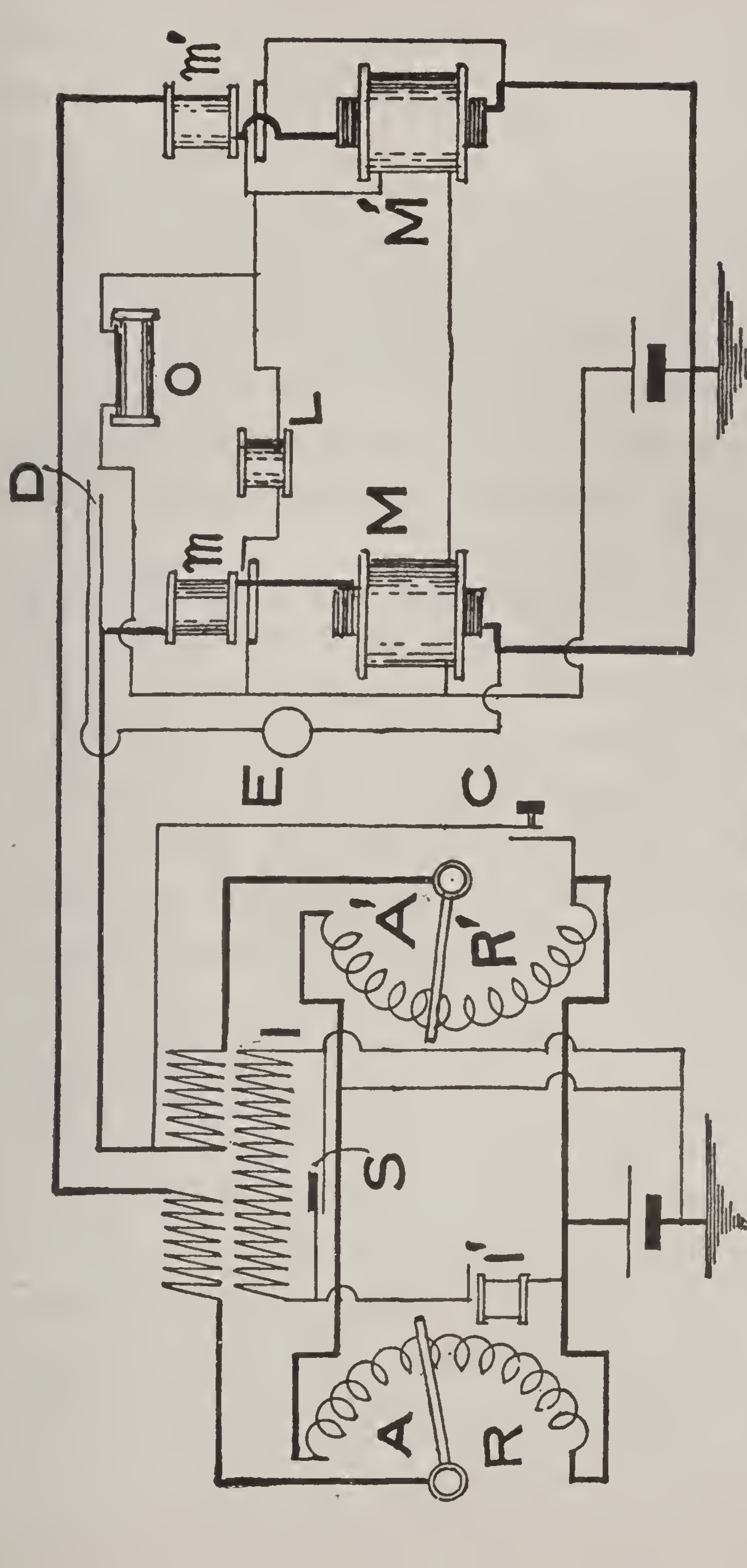


FIGURE 49a.

nets by currents passing through the coils of the plungers. The magnets themselves are separately excited.

These plungers connect to two arms similar in principle to those of the transmitter and the nature of the connection is such that every motion of the pencil upon the platen P is reproduced by a similar pencil or pen designated by a black dot in the receiver. Thus the message written upon the transmitter platen is reproduced with great fidelity upon the platen of the receiver.

The manner in which this is accomplished can best be explained by reference to the elementary diagram Figure 49a. When the instrument is in action current flows from the battery shown with the transmitter at the left, along the wires drawn as heavy lines, passing through the main magnets M, M′, and the auxiliary magnets m, m'. The actual work of writing is done entirely by the currents passing over these wires. It will be seen that the arms A, A′, as they move over the resistances cutting out or in resistance and also acting as shunts to each other, produce great variations in the current strength in the two transmitting lines. These changing currents affect the magnets M, M′, correspondingly and reproduce the writing.

In the transmitter is also included an induction coil I and its secondaries, together with an interrupter I′. The alternating currents produced by these coils are

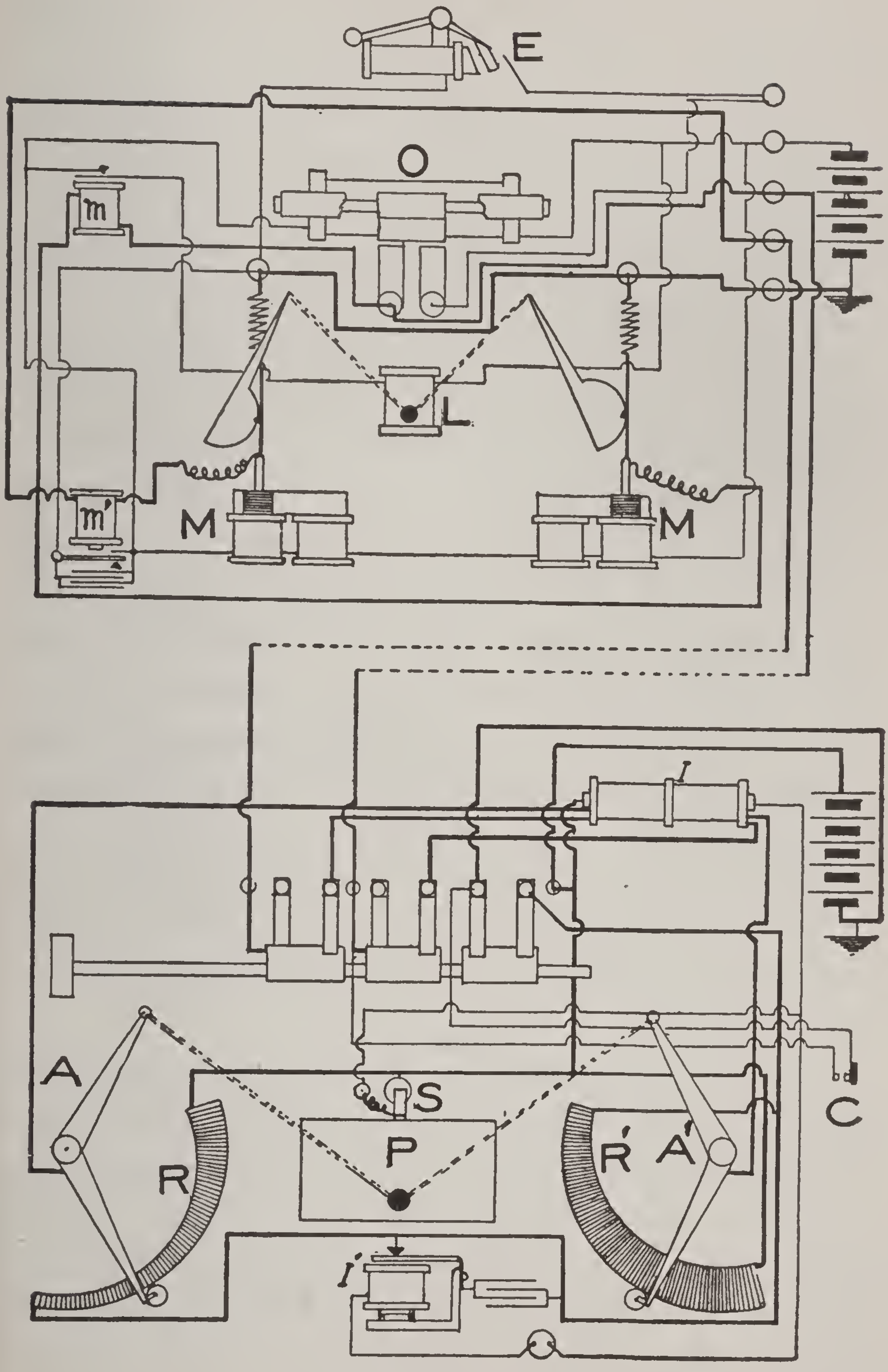


FIGURE 49b.

superimposed upon the continuous currents in the main circuit.

S is a small switch so connected that it is closed when the instrument is not writing. Pressure of the writing pencil upon the platen opens this switch and thereby strengthens the alternating currents. This increase in current strength operates the relay *m* in the receiver and causes it to open the circuit through the pen lifting magnet L. This releases the pen so that it becomes free to move in accordance with the arms of the receiver. The arrangements are also (by vibration of armature of *m*) such that the alternating currents keep the pen in a slightly vibratory state and thus reduce friction to a minimum. When the pressure is withdrawn from the platen the alternating currents become too feeble to interfere with the continuous, the relay *m* again closes the circuit through the penlifter and the pen is raised.

The object of *m′* in the receiver is to control the battery and the local circuits in the receiver. When its armature is attracted, the circuit through L, M, M′, and O are closed.

O is an electromagnetic device which shifts the paper when the circuit is broken at the end of a line. When no current is on the line, O keeps the contacts D closed. This places the bell E in parallel with M and *m*, and as these are of higher resistance than the bell, the latter rings whenever the push-button C is pressed. This is used merely for signalling.

X-RAY CIRCUIT.

A diagram of the wiring and instruments often used in connection with X-ray tubes is given in Fig. 49c. The tube itself is shown at T connected to the secondary of a strong induction coil. At the terminals of this secondary winding of the induction coil an adjustable spark gap G is provided. This is used to protect the tube against excess voltage. This gap properly adjusted will act as a shunt and the excessive current will jump the air between the spark points rather than pass through the tube.

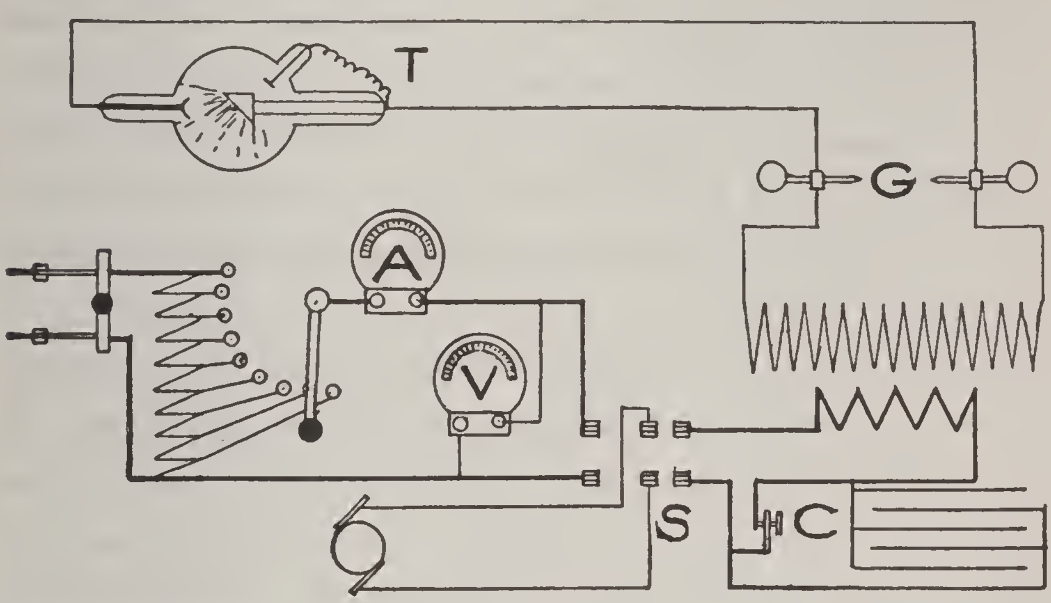


FIGURE 49c.

The exact nature of the light emitted depends somewhat upon the degree of vacuum maintained in the tube.

As a general rule tubes of low vacuum take more current, emit more light, and the light is of greater actinic power.

The light emitted from a high vacuum tube, however, is more penetrating, that is, will pass through greater opaqueness than the other.

To obtain the best results in all cases, it is therefore advisable to have on hand a stock of tubes suitable for different kinds of work.

The color of the light also varies somewhat with the nature of glass used.

In order to properly operate the tube it is necessary to send a very rapidly interrupted current of electricity at a very high voltage through it. This is done by means of a good induction coil which differs from the common form only in the nature of the interrupter.

In the ordinary induction coil in which no particular attention is paid to the exact nature of the make and break, secondary currents are induced at time of make and also of break.

An induced current is produced in the secondary whenever lines of force are increased or decreased in the winding or iron core. These secondary currents flow in one direction while the lines of force are increasing and in the opposite while they are decreasing. The value of the induced E. M. F. is in proportion to the rate of change of the lines of force. That is to say, if the current is increased from 0 to 10 amperes in 1 second it will induce secondary currents with 10 times the E. M. F. as if it were increased the same amount in the time of 10 seconds.

In the X-ray tube it is essential that the currents be practically all in the same direction and therefore

one of the induced currents must be as far as possible eliminated. The E. M. F. induced at time of break of the primary current is much greater than that at make because the circuit may be very suddenly (practically instantaneously) opened, while the make current rises comparatively slow to its full value. The break E. M. F. is therefore much greater than the make and it is the one that is used to produce the light.

The greater the difference between the two the more desirable it is for if the make E. M. F. can be kept low enough it will not send current through the tube.

The sparking which occurs at time of break of circuit is the only element that prevents instantaneous break of current, and to reduce it as much as possible, for the double purpose of preventing destructive action and increasing the suddenness of the break the condenser C is provided. Part of the current at time of break instead of continuing in the form of a spark rushes into the condenser to be discharged when the make occurs.

There are three distinct methods of interrupting the current in use. One of these is the well known method employed with ordinary induction coils or vibrating bells.

The second method is that of causing the interruptions to be made through a small motor which operates either a plunger or a disc with projections so arranged that they enter and leave a mercury contact with great rapidity. A motor is also sometimes employed

to throw a jet of mercury against a succession of contacts mounted on the inner periphery of a suitable jar.

The third method is known as the electrolytic. This is an arrangement very similar to a battery. The positive pole of the circuit is connected to one of the poles of the break (which is platinum) and the other pole of the break is a lead plate. Diluted sulphuric acid is also used. As current passes through this cell bubbles are formed on the platinum and these stop the current flow by their resistance. They immediately pass away and the current begins to flow again. The interruptions produced in this way are much more rapid than those of any other method and this method can also take care of much stronger currents. These breaks are simple and easily kept in order. Always make the platinum the positive pole, if otherwise it will soon be destroyed.

It is important to arrange that current cannot be turned on to the induction coil unless the interrupters are in action or ready to act. For this reason where motor drive interrupters are used the switch S may be arranged to close the motor circuit before the circuit to the coil is closed.

By means of the shunt resistance connected as shown any desirable voltage is obtainable from a 110 volt circuit. Start with low voltage and work up to desired voltage.

If an alternating current is to be used it must be rectified by motor generator or some other means.

CHAPTER V.

ELECTRIC GAS-LIGHTING.

Figure 50 shows the wiring of a complete metallic return gas-lighting system. I is the spark coil, which is absolutely essential. This spark coil has a relay attachment, R, which closes the bell circuit whenever the spark coil is energized. Should a ground or short circuit occur on the system, the bell will immediately

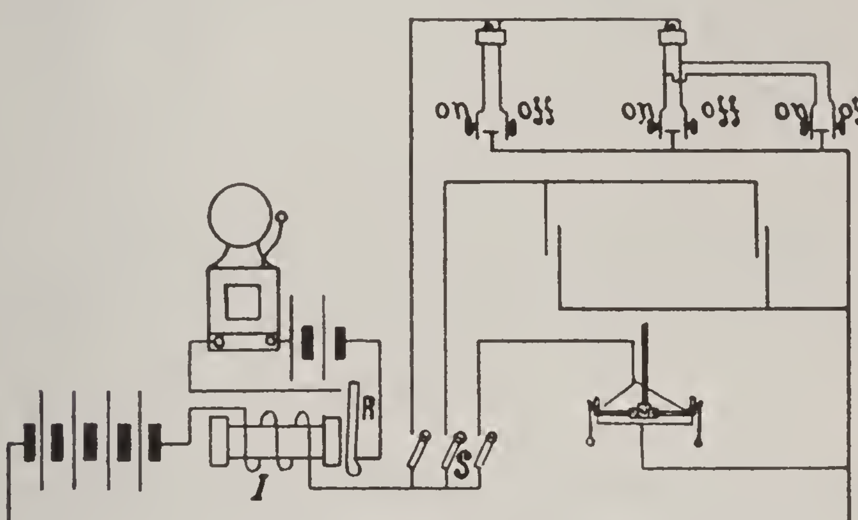


FIGURE 50.

call attention to it. By means of the switches S the system is divided into a number of circuits, and, by disconnecting the circuits, one at a time, the one out of order may be readily found.

For so-called automatic burners it is necessary to run two wires to each burner; and push buttons con-

trolling one burner may be placed in different parts of the building, as shown at top of figure. With pendants the gas can be controlled at the fixture only. Automatic burners are not very safe, as there is always a liability of gas leaking.

If a cheaper installation than the above is desired, the relay, bell, and switches S may be omitted, and the whole installation arranged as one circuit. The gas piping can also take the place of the return wire. Instead of employing a separate battery to operate the tell-tale bell, two cells of the main battery may be used; as the cells so used, however, give out much earlier than the others, it is not considered good practice to do so.

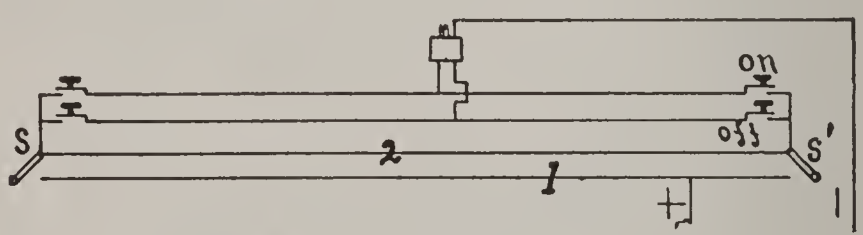


FIGURE 51.

Figure 51 shows a method which allows of two parties controlling one gas jet; the gas not being turned out until both parties are through with it. S and S′ are two switches which can make connection with the current carrying wire 1. By turning the switch S or S′ to this wire and pressing the proper button, the gas may be lit by either party. The first party to retire will press the off button, and finding no current will, after releasing the button, throw the

switch S or S′ to the wire 1. This will give current to No. 2, and when the other party presses the proper button the gas will be turned off. This method presupposes that the switch S or S′ is returned to its normal position after being used.

Figure 52 shows a system of gas lighting with an induction coil. A spark of high potential is produced which can jump many small air gaps arranged above gas jets in series. With the switch one circuit at a time is ignited. In systems of this kind about 15

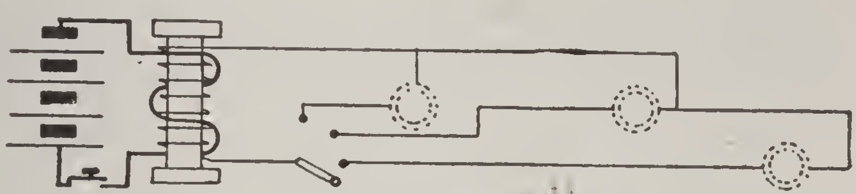


FIGURE 52.

burners are allowed to a 1 inch spark coil; *i. e.*, a coil giving a spark 1 inch in length. If possible, gas jets should be arranged so close together that they will light from one another. In such a case only a few of them need be equipped with spark contacts. Very high insulation is essential with this system, and there may be but little use for it in these days of electric lighting.

In Figure 53 are shown the connections used in the Edwards condenser system. Here all of the burners are wired in multiple and each is equipped with a small condenser. This system is mentioned in Mr. H. S. Norrie's work on gas lighting, and is said to

be successful. A suitable induction coil is used, and it need not have a very great spark capacity, and

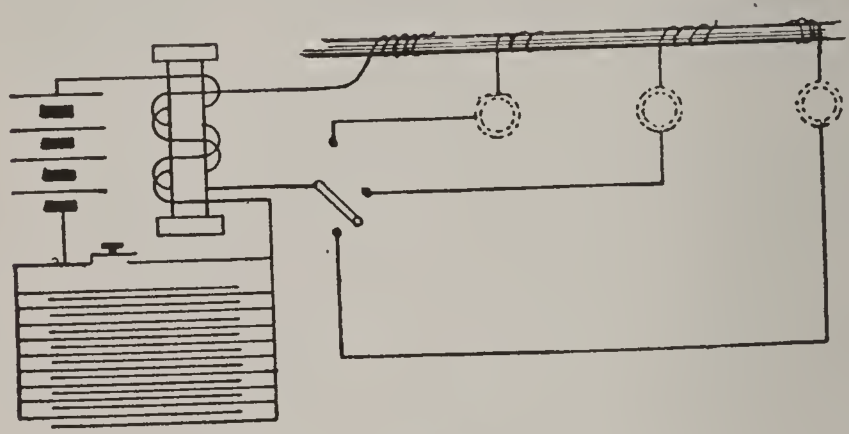


FIGURE 53.

there is much less danger of a breakdown in the insulation.

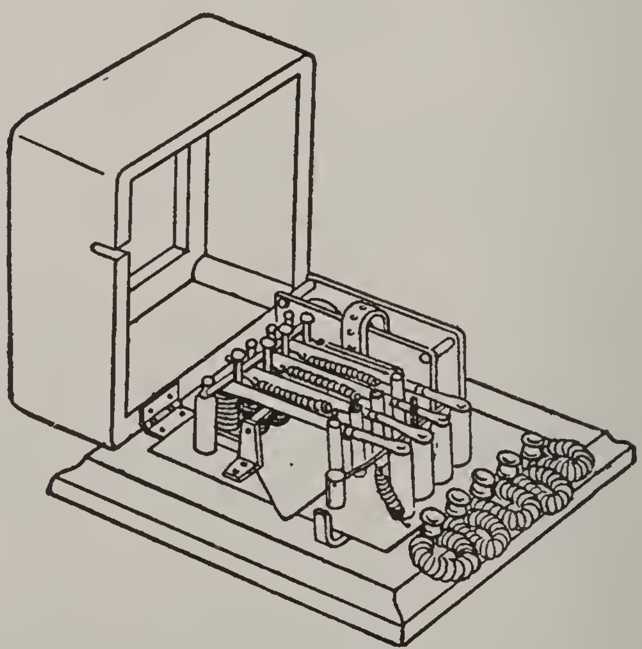


FIGURE 54.

Frictional gas lighting machines may also be used, and they are connected similar to Figures 52 and 53,

one terminal leading to ground or common return wire, and the other to the switch.

As grounds and short circuits on gas lighting systems are quite common, several forms of automatic cutouts have been devised. One of these is shown in Figure 54. The battery wire passes through a magnet which controls clockwork connected with a long pinion shaft. This clockwork is started and continues in operation while current is passing through these magnet coils. If the current lasts only an instant there will be but very little movement; while, if through a short circuit or ground the current is kept on for any great length of time, the clockwork will open the circuit.

CHAPTER VI.

PRIMARY AND SECONDARY BATTERIES.

The Figures 55 to 58 show different ways in which batteries may be grouped. Figure 55 shows the usual manner. In this way the highest E. M. F. is ob-

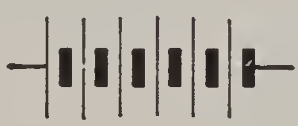


FIGURE 55.

FIGURE 56.

tained, and also the best results in all cases where the line resistance exceeds the battery resistance. It must be borne in mind that the battery has an internal resistance independent of that of the line, and this in-

FIGURE 57.

ternal resistance will modify the current quite as much as any other resistance. The battery resistance varies inversely as the surface of the plates exposed in the liquid, and directly as their distance apart.

Taking into consideration this law, we can readily see that six cells placed in multiple, as in Figure 56,

will have but one-fourth the resistance of those in Figure 55. In Figure 55 the resistance of six cells is $6 \times R$; in Figure 56 it is $\frac{3 \times R;}{2}$ in Figure 57 it is $\frac{2 \times R;}{3}$ and in Figure 58 it is $\frac{R.}{6}$ Also in any arrangement of cells the internal resistance of the battery equals $\frac{X \times R}{N}$ where X stands for the number of cells in series; R for the resistance of one cell and N for the number of groups in parallel.

FIGURE 58.

The total E. M. F. of any battery equals $N \times E$, where N stands for the number of cells in series and E for the E. M. F. of one cell. The E. M. F. of any cell is independent of its size, and while no current is flowing is independent of its internal resistance. When current is flowing, however, the drop in E. M. F. is equal to the current $\times$ the internal resistance. As the internal resistance of all primary cells is quite high, this fact must not be overlooked whenever large currents are to be used.

As a general rule cells should be so grouped that their internal resistance is nearest equal to that of

the line and instruments through which they are to work.

Where very high resistance lines are worked, as in telegraphy, for instance, the internal resistance of the battery is of little consequence, since an addition of 100 ohms resistance to a circuit of several thousand ohms would hardly be noticeable. For circuits of low resistance, such as gas lighting, it is, however, an item which must not be overlooked. The resistance of an average gas lighting circuit does not exceed a few ohms, and to place into such a circuit a battery having ten or twenty ohms resistance would obviously be poor practice. Where large currents are used it is advisable to use large cells. Placing small cells in multiple has many disadvantages, and great care must be taken that all cells are of the same E. M. F., and they should also be of the same make.

There are two general classes of primary batteries, each suited to a different class of work.

For all intermittent work an open circuit battery should be chosen. Cells of this kind will last a very long time on open circuit without deterioration, but must never be left on short circuit or used for continuous work.

Perhaps the best known of all open circuit batteries is the Leclanché cell, and the instructions here given will apply most specifically to it, but can be followed in general with all open circuit cells.

Never use more sal ammoniac than will be readily dissolved; about six ounces will be sufficient for ordinary use. It is preferable to make a saturated solution of sal ammoniac, and after filtering it through cloth or cotton wool, add about 10 per cent. of water.

Do not fill jars more than three-fourths full of solution, and keep them in a cool place, well inclosed, to prevent evaporation.

Never allow your battery to freeze.

Keep all exposed parts covered with paraffine and see that all connections are clean and tight.

Do not allow the battery to be short-circuited or run down. If this has occurred let it remain on open circuit for a few hours; it will often pick up.

If the solution appears milky it is an indication that more sal ammoniac is required. It will also be beneficial to remove the carbon and let it dry out thoroughly before using again.

Impure zincs which do not eat away evenly facilitate the formation of crystals, which greatly increase the resistance, and if not removed will destroy the action of the battery.

Dry batteries for general use are made up of the same materials as open circuit batteries, the main difference being that the material is applied in the form of a paste. They are used quite extensively for portable work. When run down some of them may be recharged by sending a current of two or three amperes through them for a few hours.

If they are dried out so that current will not flow through them an opening may be made in the shell and the cell then soaked in a solution of sal ammoniac. This will facilitate charging. The opening should be sealed again to prevent evaporation. As the shells of the cells usually consist of the zinc element, it is well to see that they are covered, or at least that two cells do not touch.

The primary battery commonly used for closed circuit work, or continuous work, is the so-called "crowfoot" or gravity battery. The copper element rests on the bottom of the glass jar. The jar is filled with clean water and enough sulphate of copper (blue vitriol) is added to give a blue tint to about one-half of the water. The blue line should be maintained about midway between the copper and the zinc, which is suspended from the top of the jar, and is usually made in the shape of a crow's foot.

When this battery is first set up it should be short-circuited for several hours, and it must be kept in action, as it deteriorates rapidly when left on open circuit.

While this battery remains in action the specific gravity of the upper solution increases. This solution should be maintained at about 25 degrees hydrometer test. If it falls below this the battery should be short-circuited for a little while. If it goes beyond this, some of the solution must be removed and the rest diluted with clear water. The resistance is

much increased by dense sulphate of zinc solution. The zinc oxide which sometimes forms on the zinc may be removed with a brush and water.

The gravity cell has a high internal resistance, and is suitable only where a continuous current flow of small quantity is desired. This cell and also the Leclanche exist in many modified forms. Enough has been said to enable anyone to select a suitable battery, and detailed instructions will be found with all batteries where such instructions are necessary.

SECONDARY BATTERIES.

Storage, or secondary batteries, as they are often called, are quite extensively used in latter day practice. It is beyond the scope of this treatise to give anything but a few working directions covering general operation. Detailed instructions applicable to the different types will accompany most cells when purchased.

The E. M. F. of secondary batteries will average a little over 2 volts. On discharging, the E. M. F. should not be allowed to fall below 1.8 volts.

The charging should proceed slowly, and should never be carried beyond 2.5 volts.

The charging E. M. F. should not exceed that of the battery more than 5 per cent.

Cells should not be discharged more than two-thirds of their capacity. They should never stand uncharged.

In battery rooms all exposed metal work should be painted as a protection against acid fumes.

Wooden floors should also be protected against acid.

If charging is continued after the active material has been used up, oxygen and hydrogen gas will be given off.

Pure sulphuric acid should be used, and this should be diluted with distilled water. Pour the acid into the water slowly. Never pour water into acid, as much heat is generated.

Whenever necessary, replenish evaporation with distilled water and mix well, as otherwise the water will float on top.

Two methods of measuring the internal resistance of batteries are shown in Figures 59 and 60. In Figure 59 A represents an ammeter and V a voltmeter. Instruments for this purpose must be chosen suitable to measure the small currents and E. M. F. likely to be used, and must have a scale sufficiently large to admit of reading fractions of volts and amperes. To make the test, first close the circuit through the voltmeter. This gives us the E. M. F. of the whole battery, and may be called E. Next close the circuit through the ammeter and note the current reading; also at the same time note the reduced reading of the voltmeter and call this E′. The internal resistance of the battery is equal to $\frac{E - E'}{A}$, where **A**

is the number of amperes flowing through the ammeter, and the other two symbols as above. The readings must be taken in a very short time, or polarization will modify both current and voltage. If the ammeter used above is of very low resistance, an additional resistance should be placed in circuit with it to prevent excessive current flow.

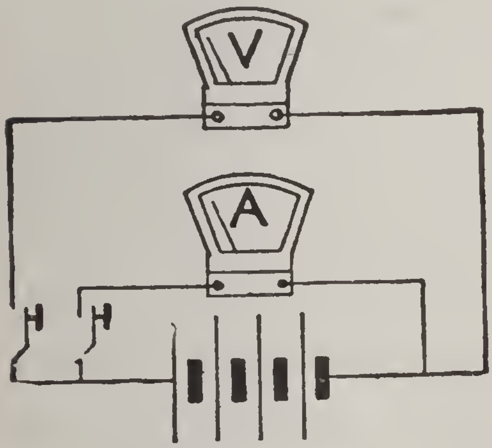


FIGURE 59.

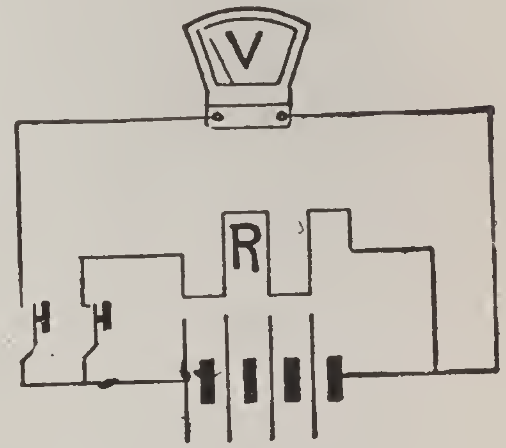


FIGURE 60.

In Figure 60 no ammeter is needed, but the resistance of R must be known. Take the voltmeter reading as in Figure 59 and call it E. Next take the voltmeter reading with current flowing through R and call it E′. The internal resistance of the battery is $\dfrac{E-E'}{\frac{E'}{R}}$. In other words, divide E′ by R, which gives the current flowing through R; then divide the difference between E and E′ by this current. The result will be the battery resistance.

A comparative test as to the value of the different batteries may be made in the following manner: Procure the same number of cells of each kind to be tested. A suitable resistance and a voltmeter with a suitable scale must also be procured, and connections made as in Figure 60. The voltmeter should be of quite high resistance, so the current flowing through it will not materially affect the battery. The resistance should be about equal to the battery resistance. This will allow a current to flow which will gradually polarize any open circuit battery. When all is ready, close the circuit through R, and at regular intervals, of say one minute, note the fall in E. M. F. on the voltmeter until the battery is nearly polarized. Now open R and in the same way take readings at regular intervals, until the battery regains its former E. M. F.; or, if this is too long, for any convenient time.

The figures obtained may be plotted in curves, as shown in Figure 61, where the time is plotted horizontally each division representing one minute, while the drop in E. M. F. is plotted vertically, two divisions representing one-tenth of one volt.

The figure shows the polarization and recovery curves of a Laclede cell having an initial E. M. F. of 1.2 volts, and discharging through a resistance of 3 ohms. During the first minute the E. M. F. fell to .78; during the second to .68; third to .62; fourth to .58; fifth to .55; and at the end of twenty-six minutes it had fallen to .3.

Upon opening the circuit the E. M. F. rose during the first minute to .47, and during the second to .5; and then in a more gradual and steady manner as indicated by the curve.

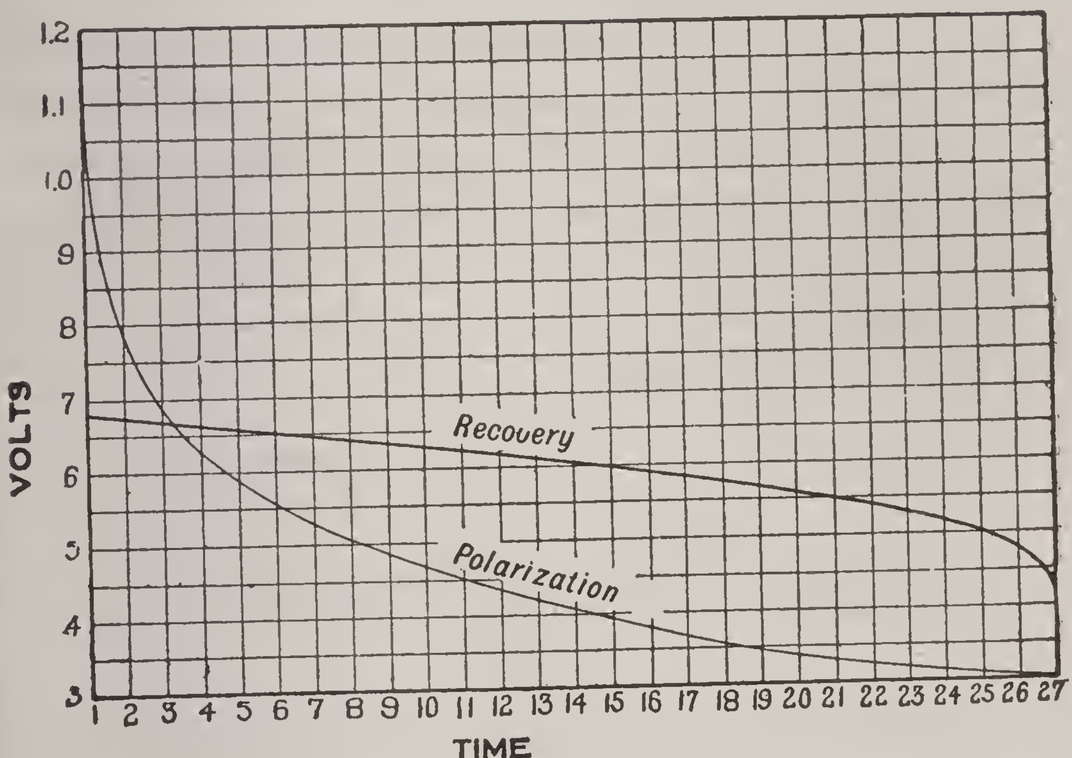


FIGURE 61.

If all batteries are tested with the same resistance and voltmeter, and given the same time, the result must be fairly comparative.

CHAPTER VII.

CONNECTING UP—LOCATING TROUBLE.

Figure 62 shows the rough wiring used to connect an annunciator with a call from each of the floors 1, 2, 3, 4, and also a call from the office to each of those floors. This figure is introduced to illustrate a

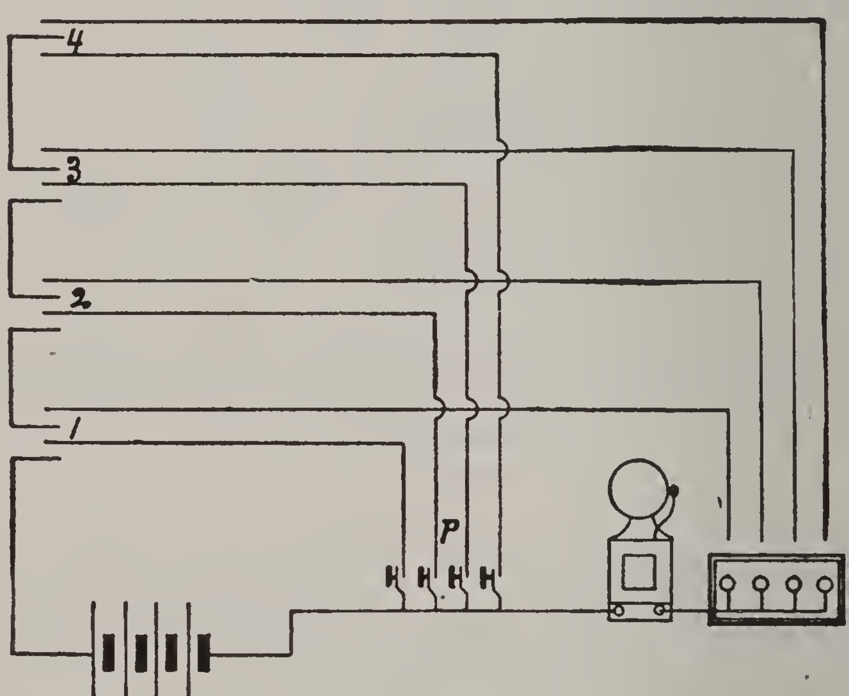


FIGURE 62.

method of testing to find the proper wires to make connections, and it will be assumed that all of the wires are concealed and all are of the same color, so that it is impossible to trace out any part of the

wiring. Let it also be assumed that the party who is to connect the system did not install the wiring, and knows nothing about any part except the purpose for which it is installed.

The first step should be to separate the wires at all outlets so there may be no accidental connections which would cause confusion. The next step is to connect the battery to the two battery wires as shown, which will very likely be found without any trouble. Now go to floor 1 and bunch all wires found there, testing each wire to all other wires with a portable bell before connecting. If a ring is obtained it is an indication of a short circuit or wrong connection, which must be located and corrected before proceeding farther. Next proceed to the push buttons, P, and with the test bell find the wire coming from 1; when the bell is connected to the wire coming from 1 and to the battery wire a ring will be obtained. Now take up the annunciator wires and find the wire coming from 1 in the same way.

Having now found one wire which rings with two others, this must be the battery wire, and may be connected to one side of all the pushes, and to the annunciator through the bell. The other two wires may be marked and the connections at 1 removed. After this has been done, connect the two wires coming from 1 each to its proper place, push 1, and drop 1 respectively, and fix the push button so it will keep the circuit closed. Had this been done without

first opening the connections on floor 1, a short-circuit would have been the result.

Now return to 1 and find the wire which rings the annunciator, and also the one which rings the test bell without disturbing the annunciator. The one wire used in common for both is the battery wire, and connects to one side of the bell and also to the push for annunciator. The wire leading to push P is to go on the other side of bell, while the one leading to annunciator goes to the other side of push button. The fourth wire must necessarily be the battery wire leading to the floor above, and is to be connected to battery wire coming from floor below.

For these tests a bell to act either single stroke or vibrating is very useful, especially when the annunciator is so far away that the ringing of its bells cannot be heard. A bell of this kind will indicate at once whether the wire through which it rings is connected with the annunciator or the push buttons, since it will ring vibrating in series with the annunciator bell and single stroke in connection with the push button wire.

The foregoing tests represent a great deal of time and labor, much of which may be avoided by using wire of one color for the battery wire and a different color for all the other wires on each floor. For Figure 62 this would require five colors. With wires arranged this way, the steps necessary to con-

nect up the system will be: First connect the battery wires on the different floors so that there will be one continuous wire from the battery to the fourth floor. While doing this note the color of wire used on each floor, so that the annunciator and push button wires may be connected up accordingly. After connecting these and the battery, return to each floor and set up the bell and connect it to the battery wire. Now touch one of the two remaining wires to the bell; if it rings it is the wire coming from the annunciator, and the other is the proper wire to connect to the bell.

Always locate the battery as near as possible to the push buttons. In this way the chance of leakage may be reduced to a minimum, since one wire only is exposed for any considerable length, the other being cut short by the pushes.

When one is alone a bell and battery is a very valuable help in fish work. Insert one piece of wire coming from the battery into the ceiling where it is expected to bring the wire to. Connect the fish wire to the other side of the battery and proceed in the usual way. When the two wires meet the bell will ring.

LOCATING TROUBLE.

While looking for trouble always work according to a fixed plan; haphazard testing and guessing will usually waste time. In all cases the most important thing to ascertain is whether the battery is in work-

ing order. If there are several bells and any one of them is working properly, the battery may be set down as all right. If there is no bell in operation, and none at hand, the most convenient way to test the battery is by "tasting"; arrange wires so that both poles come in contact with your tongue. If the battery is in order you will notice a peculiar taste, and a little experience will enable anyone to determine, approximately, whether the current is in proportion to the number of cells employed.

It will be well to avoid "tasting" circuits provided with an unusual number of cells and large magnets or spark coils, as the taste is apt to be very strong, especially if the wires are allowed to meet on the tongue and then break. If no current is obtained at the battery, examine the binding posts and connections; see whether each jar is properly filled and whether any of the zincs have been eaten away, or covered with crystals, which often causes a total cessation of current. If the battery is not found defective in any of the above points it may be entirely run down, either from overwork or a short circuit.

Some idea of the trouble may often be gained by questioning parties interested. If the bells stop suddenly it would indicate a broken line or a short circuit. If any bell were ringing continuously for a long time it would run the battery down. If the battery has been merely run down it will pick up in a short time if left on open circuit. A small galvano-

meter is very useful and will soon indicate whether a battery is picking up; it may also be used to test each cell separately. In any case, it is best to have the battery in good working order before looking elsewhere for the cause of trouble. If the battery is in order the next step (if there is but one bell) should be to examine the bell and push buttons; see that contact points are in order and that the bell is properly adjusted; also examine the line connections and see that they are clean and tight. A portable battery is very convenient, and with it one can quickly determine whether the bell is in order.

If, after the foregoing, the bell still fails to work, the trouble must be looked for in the line, and it will be well to examine the wires near bell and push buttons, as these wires are handled quite often for various reasons, and will often be found broken quite close to their connections. Splices are also quite often to be found quite close to terminals, as wires are often cut short when installed. When there are several bells and all fail to work, the inference would naturally be that the main battery wires are either broken or short circuited. If the battery is in good working order, one may be certain that no short circuit exists, and an open circuit must therefore be looked for.

From the many foregoing diagrams it will be seen that in all ordinary multiple bell systems, one wire coming from the battery leads to the bells and the other to the push buttons; this does not mean that

the bells must all connect to the same wire and the push buttons to the other, since, in Figure 63, the location of any bell and its push button might be exchanged without hindering its operation. In Figure 63, 1 and 2 are the battery wires connecting with bells and buttons as shown. Suppose none of the bells will ring and we have come to the conclusion that one of the battery wires is broken; the best way to locate a break in the main wires is with a test bell, starting from the battery end of the line. At any

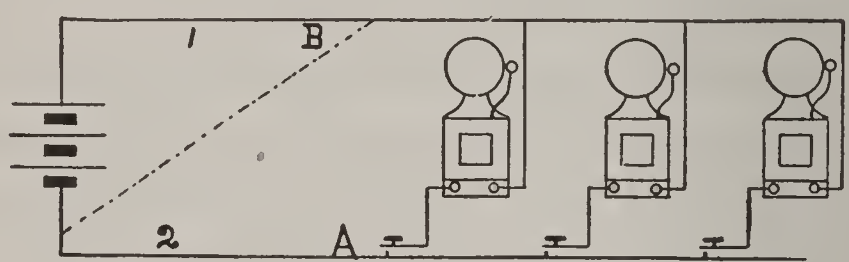


FIGURE 63.

convenient place where both battery wires are accessible, say at A and B, connect the test bell; a ring will show that the line between it and battery is in order, while failure to ring would indicate the break to be between it and the battery. Suppose no ring has been obtained and we now wish to ascertain which one of the main wires is broken; we can do so by running a temporary wire from B back to the battery as shown by the dotted lines. If the wire (1) is not broken between B and the battery, a ring will be obtained when connections are made to the opposite battery pole. If the wire is broken no ring can

be had from either battery pole; but when the temporary wire is connected to the wire and pole of the battery in which the break is, the whole system will be in working order.

If a short circuit exists, say at C and D, Figure 64, one way to locate it is by cutting a bell into the circuit at the battery. If the battery has been run down by the "short," as will likely be, one must either recharge or wait for it to pick up, unless an extra battery is at hand. Having connected the bell near

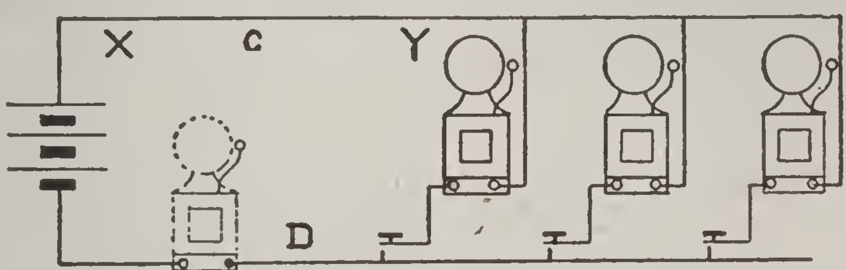


FIGURE 64.

the battery, we can now cut one of the main wires at any available place. If this stops the bell ringing, the short circuit is farther from the battery; if it does not stop the bell the short circuit is between the cut and the bell. If a portable battery is at hand, it and the bell may be carried about and cut into the circuit wherever desired. In this case the regular battery should be disconnected and the battery wires connected together. If the short circuit exists at C and D, as aforesaid, and the battery is cut in at X, a ring will be obtained; while when we get beyond the short circuit and cut in at Y, no ring

can be obtained. By making several tests as outlined above, the seat of trouble can be very closely located. The foregoing instructions assume that the wiring is concealed or that a close inspection is very difficult. Short circuits will generally be found where wires cross metal pipes or bars, or where one staple holds two or more wires. Wire lath is also a very prolific cause of short circuits, and it must be borne in mind that two grounds on opposite wires are equal to a short circuit. As a matter of fact if a bell system can be kept clear of grounds, there will be but very little trouble from short circuits.

An easy and also a sufficient test for battery bell systems can be made by means of a strong magneto. Connect the magneto in place of the battery and give it a few sharp turns; if a ring is obtained the insulation between opposite poles is weak. This may be caused by the leak across the surface of a push button or kindred device, or it may be the result of poor general insulation, both poles being slightly grounded. A ground on one side only would not be discovered in the above test.

To test the insulation resistance to ground, connect one wire of the magneto to a convenient water or gas pipe, the former being preferred on account of the poor conductivity often caused by rust or red lead in the joints of the gas pipes; the other wire connects to the whole bell system without the battery. If, on turning the magneto, a ring is ob-

tained, it is an indication of poor insulation resistance, and very likely some of the wiring is located in a damp place or in contact with metal or other grounded material. By disconnecting one of the battery wires one can easily determine on which side of a system a ground may be located. All grounds should be removed, as they are the cause of leaks which run batteries down, and in time may cause a broken wire through electrolytic action. In telephone systems one or more grounds may also seriously interfere with the talking qualities of a line, even if the grounds are all on one side of the circuit.

CHAPTER VIII.

MISCELLANEOUS.

Whenever a current is flowing in a wire it produces lines of force surrounding that wire. If the current in the wire flows away from the observer the lines of force will encircle the wire from left to right, *i. e.*, clockwise. (See Figure 65.) Lines of force always enter a magnet (compass needle) at the south seeking pole and leave it at the north seeking end.

FIGURE 65.

From this it follows that if a compass be held under a wire in which a current is flowing from you the north seeking end of the needle will deflect toward the left; while if the current is flowing toward you it

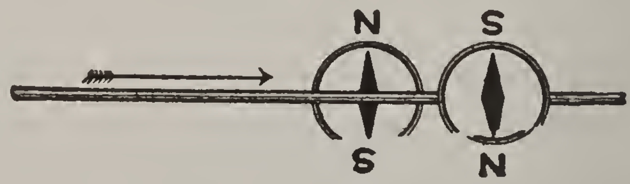


FIGURE 66.

will deflect toward the right. If the compass is held above the wire the deflections will be the reverse of the above, as shown in Figure 66.

Unless an extremely delicate compass be at hand, this method of determining the directions of currents in wires will be confined to comparatively large currents. If there are any magnets in the circuit, and if we know the direction in which they are wound, we can very easily determine the direction of the current, since the relative direction of current and magnetism will be as in Figure 67.

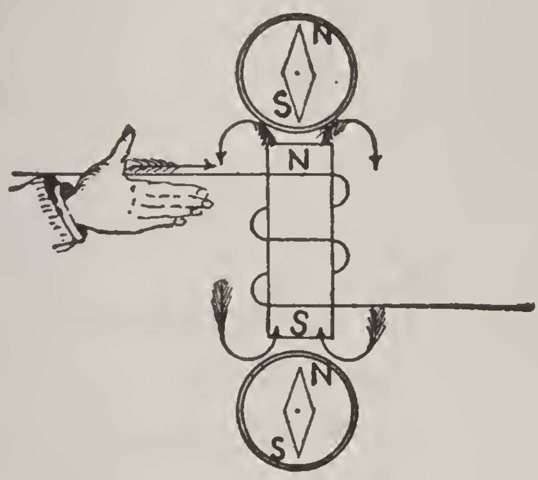


FIGURE 67.

If there is no magnet available, one may be temporarily constructed out of a screwdriver or pocket-knife by taking a few turns of the current carrying wire around it. If no compass is at hand, one can be made from a piece of cork and a steel needle set afloat in a cup of water, the needle being first magnetized.

If the right hand be held above a wire as in Figure 67, in which the current is flowing from you and the winding as shown in the figure, the north pole of

the magnet will be as shown. If the direction of winding be reversed, or the direction of the current. the north pole will be at the other end.

All magnets have a retarding effect on alternating or intermittent currents. With an arrangement as shown in Figure 68, a lightning discharge will generally jump the small distance between the points of the lightning arrester rather than pass through the

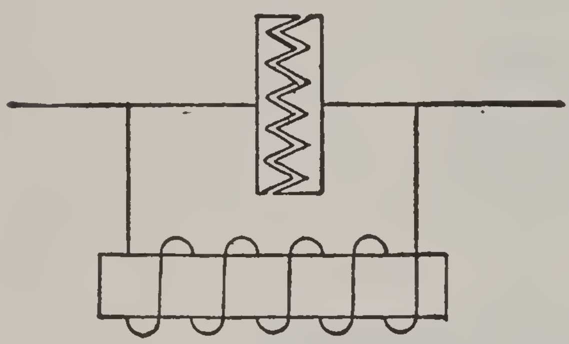


FIGURE 68.

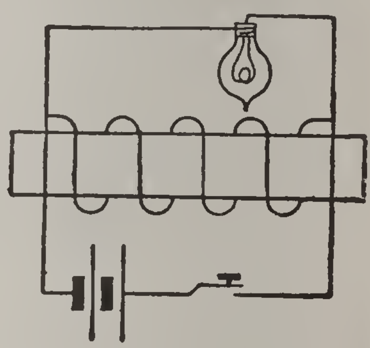


FIGURE 69.

coils of the magnet. When, however, a current has once been started around a magnet it has a strong tendency to continue, and will manifest itself in a long spark if suddenly interrupted, as in a gas-lighting spark coil, for instance. Figure 69 is drawn to illustrate this, and the magnet there shown is of very low resistance compared with the lamp shown in multiple with it. If the battery circuit is closed the magnet will be energized, but no appreciable current will flow through the lamp. If now the battery circuit is suddenly opened, there will be a strong current discharge through the lamp, causing it to flash up for an instant.

Figure 70 is designed to illustrate some of the differences in electrical currents. The winding of magnet A, if properly proportioned, will be found to be almost impenetrable to rapidly alternating or intermittent currents, while it may offer hardly any resistance to continuous currents. A continuous cur-

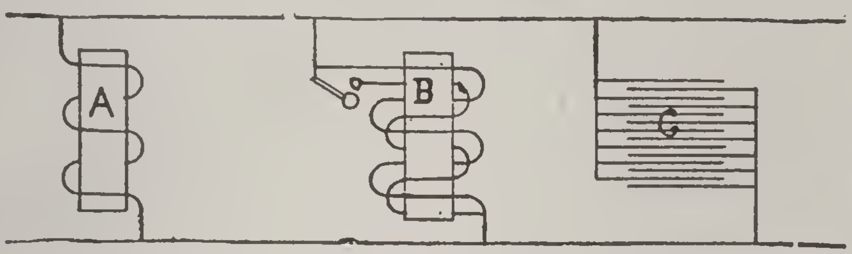


FIGURE 70.

rent working an ordinary bell would be much retarded by it, however, and the bell would work very slow. B has two windings opposed to each other. If one winding only is in circuit it will act similar to A; if

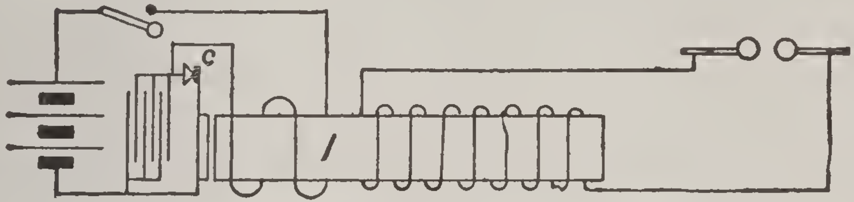


FIGURE 71.

the switch on the second winding is closed there will be but little retardation. The condenser C entirely prevents the passage of continuous currents, but telephonic currents pass readily through, and polarized bells may also be made to ring through it.

Figure 71 shows the plan of an ordinary induction coil. The iron core when energized attracts the interrupter, and this breaks the current at C, as in a

vibrating bell. At every make and break in the primary circuit secondary currents are induced in the fine secondary winding. The circuit breaker is bridged by a condenser in order to reduce the sparking to some extent. With cheap coils the condenser is usually omitted.

Two wires carrying current in the same direction will attract each other, while if currents are in opposite directions they will repel each other.

A leak to ground on a positive wire will gradually destroy it; the negative will not be affected much.

An easy method of determining the direction of current consists in letting the current pass through a little water confined in a cup. The current will flow from the positive pole to the wire at which small hydrogen bubbles appear, which is the negative. This method is not applicable to low voltage systems.

The contacts of bells, relays and other devices which produce frequent interruptions in current, should consist of platinum. To determine whether they are platinum or not, drop a little nitric acid on them; this acid will not affect platinum, but will attack German silver and other imitations.

A continuous current will carry an arc much longer than an alternating current. It also produces a chemical action directly in proportion to its amount in amperes.

A magnet in an alternating circuit will greatly reduce the current, and the iron will be heated by the

frequent reversals in the direction of magnetism. If the magnet is large and the frequency of the alternations is very great, only a very small amount of current will flow. The magnetism has no such effect on continuous currents. The heat generated in a continuous current magnet is produced by the resistance in the wire only, and the current flow depends on this resistance only. Alternating currents are also greatly retarded and diminished by lead covered wire or wires run in iron pipe. These wires act as condensers and currents are also induced in them. Whenever it is necessary to run wires in this way, both wires should be enclosed in the same sheath or pipe. Continuous currents are not affected in this way except for an instant at make or break.

USEFUL FACTS AND FORMULAS.

In any direct current circuit the current equals the electromotive force divided by the resistance, $I = \frac{E}{R}$. One application of this law is indicated in Figure 72, where the voltmeter V is used to measure current. The value of R being known, the current flowing through R is equal to the voltmeter reading, E, divided by R, the resistance.

From the formula $I = \frac{E}{R}$ two others are deduced. In Figure 73, knowing the value of the electromotive

force E, and current I, we can find the resistance R by dividing E by I, $R = \frac{E}{I}$. Knowing the current I and the resistance R, we can find the electromotive force E, by multiplying I with R, $E = IR$.

The volts lost in any circuit equal the resistance of that circuit multiplied by the current.

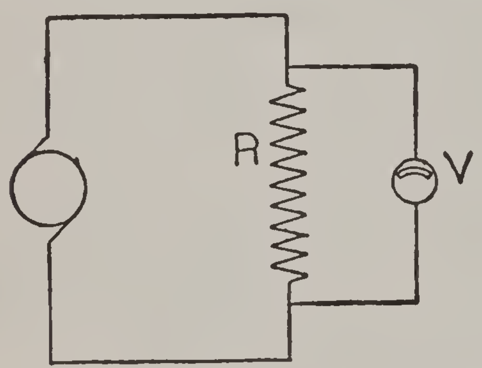


FIGURE 72.

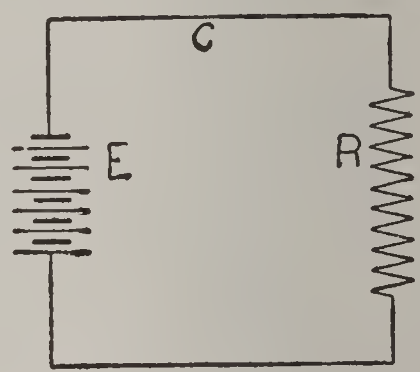


FIGURE 73.

Currents of electricity divide among derived circuits in proportion to their conductivities, which is the inverse ratio of their resistances; *i. e.*, the lower resistance takes the most current. The joint resistance of two circuits in parallel is equal to the product of the two resistances divided by their sum.

In Figure 74 $\frac{5 \times 5}{5 + 5} = 2\frac{1}{2}$.

The joint resistance of any number of circuits in parallel if all are equal, may be found by dividing the resistance of one circuit by the total number of circuits. The joint resistance of any number of cir-

cuits in parallel, whether they are equal or not, is the reciprocal of the sum of the reciprocals of their resistances. Joint resistance equals

$$\frac{1}{\frac{1}{R}+\frac{1}{R'}+\frac{1}{R''}}$$

where R, R′, R″, are different resistances. The reciprocal of a number is 1 divided by that number, thus one-tenth is the reciprocal of 10.

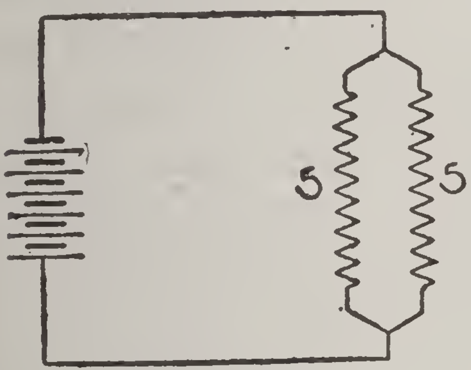


FIGURE 74.

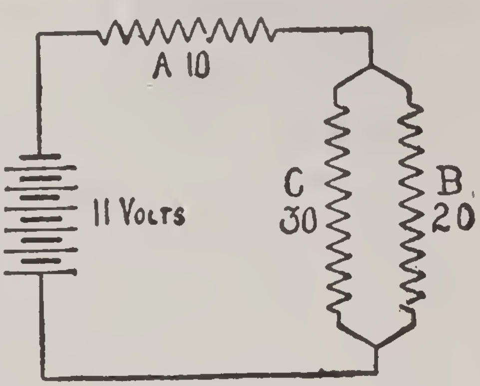


FIGURE 75.

To find the total current, Figure 75, we must first find the joint resistance of 20 and 30, which, according to the above formula, is 12. Next add this to the other resistance 10, in the circuit, and divide the electromotive force 11, by this sum. The result is one-half ampere, of which three-tenths will pass through B and two-tenths through C.

The multiplying power of a shunt is the ratio of the total current flowing in the circuit to that part of it which flows through the ammeter. The shunt

required to give a certain multiplying power is found by dividing the resistance to be shunted by the multiplying power desired minus 1. Thus, if the multiplying power desired is ten, we divide by 10 — 1, which is 9. If the resistance to be shunted is 100 ohms, the proper resistance of the shunt is 100 divided by 9, which is 11 1/9 ohms. Nine-tenths of the current will flow through this shunt and 1/10 will flow through the ammeter.

The amount of work done by a current of electricity is measured in watts. To determine the number of watts multiply the square of the current by the resistance, or $W = I^2R$. For instance, the heat generated in a wire is proportional to the square of the current; thus, doubling the current will produce four times as much heat. Other formulas for determining the watts deduced from the above, using Ohm's law, are: $W = I\,E$, or the current times the electromotive force, $W = E^2/R$, or watts equals the electromotive force squared divided by the resistance. One horse-power equals 746 watts. To reduce to horse-power divide the watts by 746.

The magnetism produced in an iron core is to a certain extent proportional to the number of ampere turns (current times the number of turns of wire) but when the point of saturation is reached, although the magnetizing force is increased, still there will be but little increase in magnetism. Figure 76 illustrates the increase in magnetism in wrought iron and

cast iron, the magnetizing force (ampere turns) being represented by the distance measured along the horizontal line and the resulting magnetism by the distance along the vertical line. This is important to bear in mind when adjusting field coils or rheostats on dynamos or motors.

The circumference of a circle is found by multiplying the diameter by 3.1416, or roughly 3 1/7.

The area of a circle is found by multiplying the square of the diameter by .7854, or the square of the radius by 3.1416.

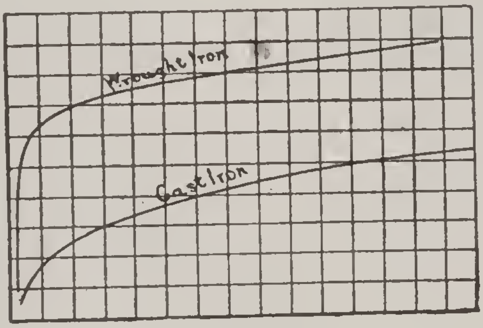


FIGURE 76.

The circular mils in a wire may be found by multiplying the diameter in mils (1000 mils per inch) by itself.

To convert circular mils into square mils multiply by .7854.

To convert square mils into circular mils divide by .7854.

The weight per mile of pure copper wire is $\frac{d^2}{62.5}$ where d is given in mils.

The resistance of copper wire increases 21/100 of 1% for each degree rise in Fahrenheit.

The resistance per mile of pure copper wire is about $\frac{54882}{d^2}$, d being in mils.

The weight of iron wire per mile is $\frac{d^2}{72}$ where d is the diameter in mils.

The resistance per mile of galvanized iron wire is about $\frac{360000}{d^2}$, d being in mils; or about seven times that of copper.

The resistance of German silver is about thirteen times that of copper.

CHAPTER IX.

ELECTRIC LIGHTING.

Figure 77 shows what is known as the tree system of electric light distribution. The wires at the lowest floor must be of sufficient capacity to carry the total current. At each floor or succeeding center of distribution the size of mains may be reduced, suitable

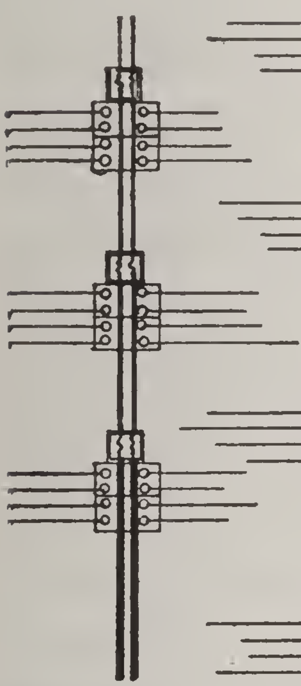


FIGURE 77.

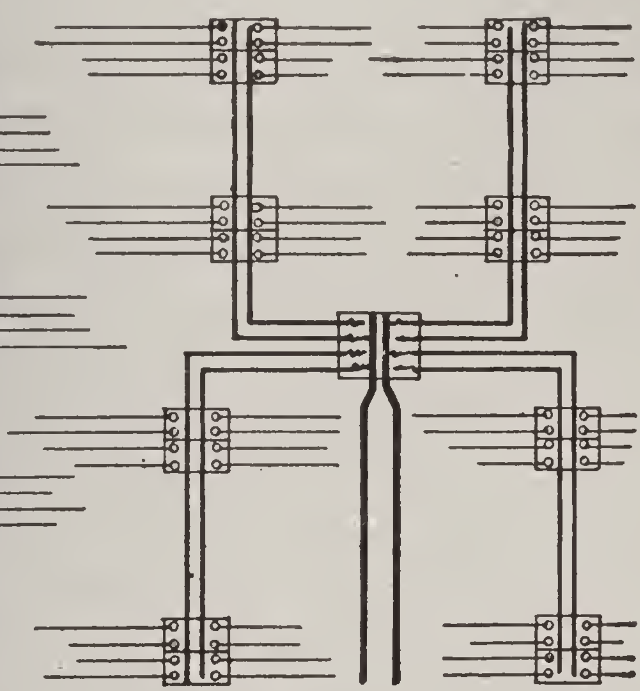


FIGURE 78.

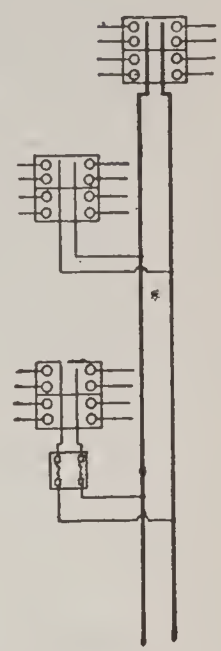


FIGURE 79.

cutouts being provided as shown in the diagram. This system is not to be recommended, as it will result in great difference of potential between those branch circuits nearest the dynamo and those at the

extreme end of the system. When the mains are fully loaded, the nearest lamps will either burn too bright or those at a greater distance be dim.

This difficulty is largely overcome by the arrangement shown in Figure 78.

Figure 79 shows a system of distribution which is very often used. The mains are run direct from the dynamo, or street service, to the last center of distribution without changing size of wire. While this system has some of the disadvantages of the tree system in regard to drop, still the losses are greatly reduced owing to the much smaller losses on the mains between those centers farthest away from the source of supply. If the mains are of small size they may be run directly through the branch blocks at the various centers, as shown at the upper part of the figure. If the mains are too large to be run directly through the blocks, either of the methods shown in the lower part of the figure may be used, that shown at the bottom being preferable for, in case of a short circuit, across the contacts on the branch blocks, the smaller fuse will blow, while if the method shown in the center is used the main fuse will blow. This arrangement also allows any center to be disconnected for testing without affecting the remainder of the circuits.

Figure 79a shows how a two wire system may be converted into a three wire. One extra wire will have to be run. If the change over results in doubling the voltage of the system this wire will not require to be

as large as the original wires and should be connected to the neutral i. e. should run to all of the cutouts as shown in cut.

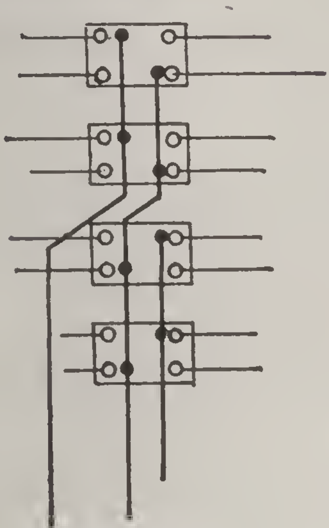


FIGURE 79a.

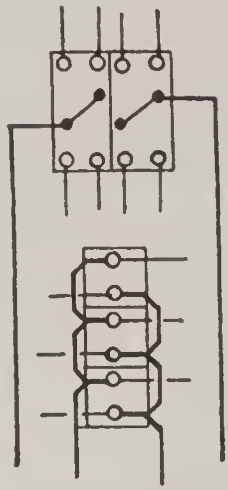


FIGURE 79b.

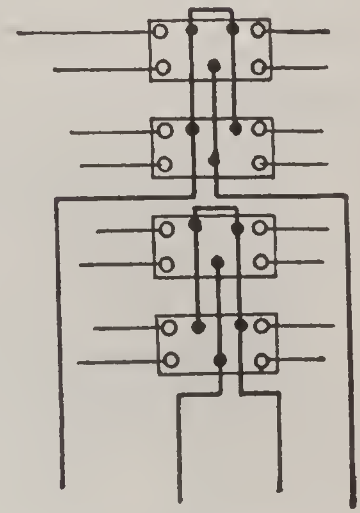


FIGURE 79c.

Figure 79b shows method of arranging cutouts so that all branch wires on any side of box are of the same polarity. This is frequently of use in electric signs where large numbers of wires are often bunched.

In Figure 79c a three wire system is shown converted into a two wire. As this usually is accompanied by a

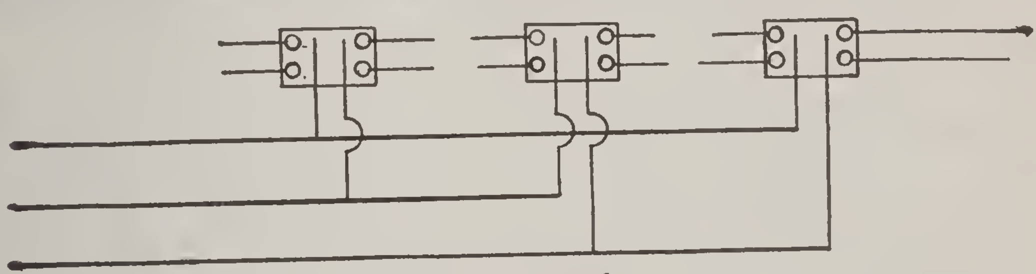


FIGURE 79d.

reduction in voltage and a consequent increase in current for the same number of lights it will likely be necessary to run an additional wire and divide the cutouts as shown.

Figure 79d shows the manner of connecting cutouts to a three phase system where cutouts are scattered along the line. Particular attention must be given to see that lights are as near as possible balanced between the phases.

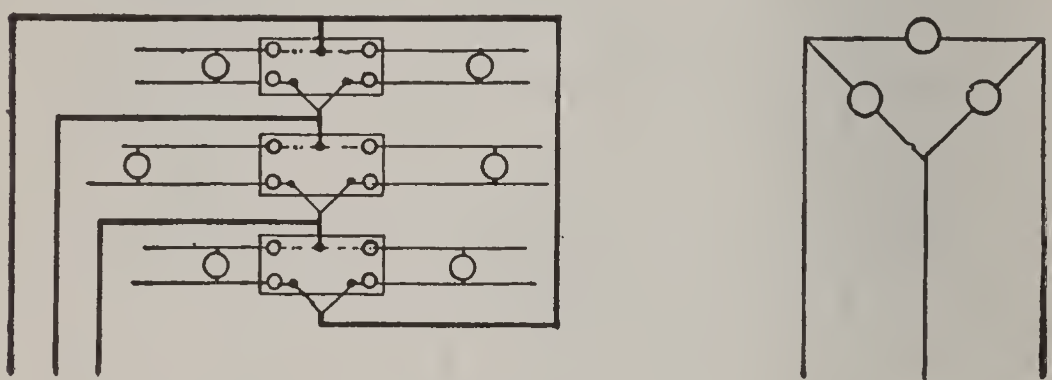


FIGURE 79e.

The delta connection for cutouts grouped together is given in Figure 79e. By tracing out the diagram it can readily be seen that the cutout connections are similar to the connections of the single lamps shown at the right.

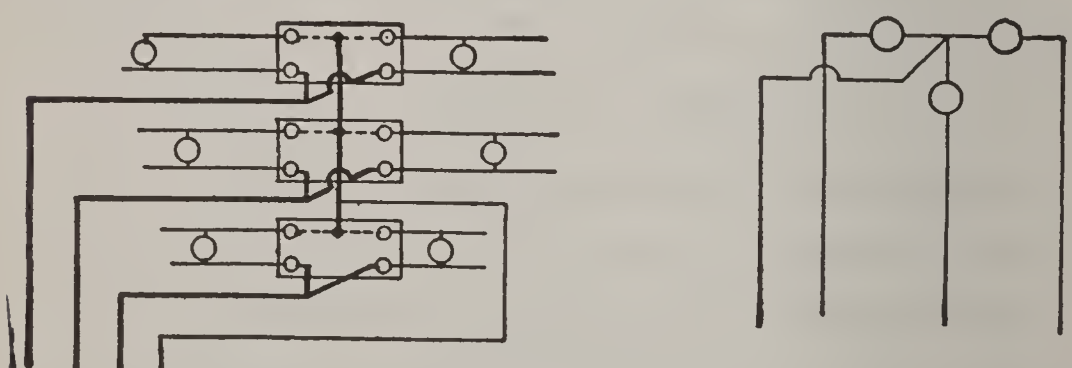


FIGURE 79f.

The voltage of lamps used in connection with this arrangement must be the same as that of the phases.

The star connection of cutouts is given in Figure

79f. If this connection is used it should have a balancing wire as shown.

The voltage of lamps to be used in connection with this system must be equal to the voltage of the phases divided by 1.73. This method is not generally used.

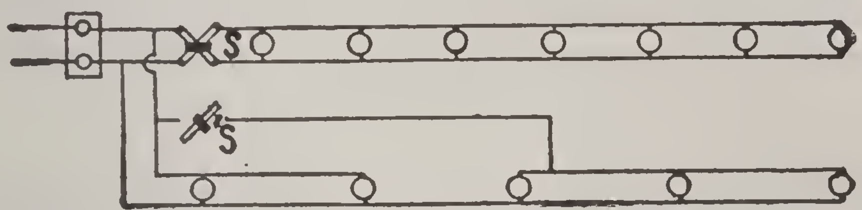


FIGURE 80.

Figure 80 shows a two-wire circuit with seven lights controlled by a double-pole switch, S; three lights controlled by a single-pole switch, S′; and two lights not controlled by any switch.

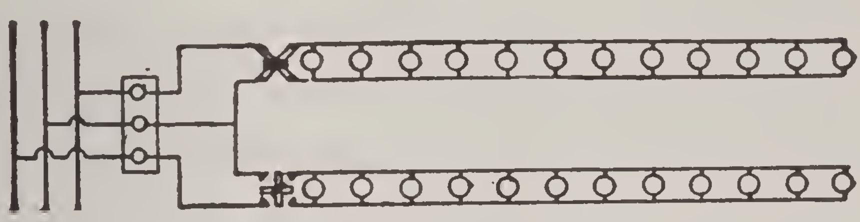


FIGURE 81.

Figures 81 and 82 show three-wire circuits. Figure 81 is arranged with double-pole switches, each switch completely disconnecting the wires controlled by it. In Figure 82 only the two outside wires are broken, the neutral wire remaining intact. When single-pole switches are used in connection with three-wire systems, they should be placed on one of the outside wires, as the neutral wire is nearly always

grounded. No switch must ever be connected so as to make it possible to break the neutral wire without also breaking the outside wires at the same instant.

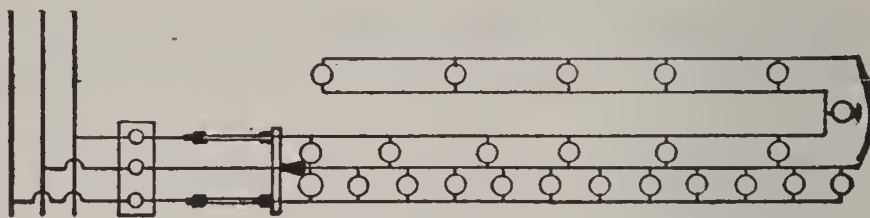


FIGURE 82.

Figure 83 shows a double-pole method of controlling a circuit from two places.

FIGURE 83.

In Figure 84 a similar arrangement is shown acting single-pole and arranged at one end for a throw-over knife switch and at the other for a three-way snap switch.

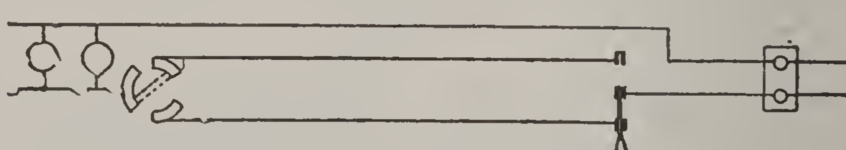


FIGURE 84.

By Figure 85 the same result is accomplished, and in some cases this method may be more saving of wire than Figure 84; but it cannot be used in connection with direct-current arc lamps, as the polarity may be reversed in turning lamps on and off.

Figure 86 shows a method of controlling a circuit from any number of stations. Any number of double-pole switches, as shown in the center, may be cut into

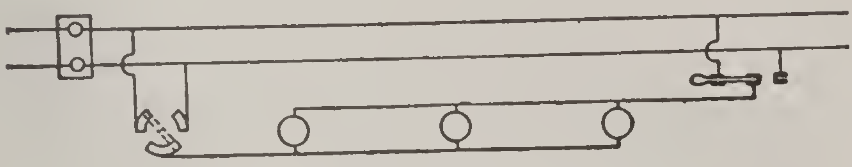


FIGURE 85.

the line. Snap switches as shown in Figure 87 may also be used in place of the throw-over knife switch.

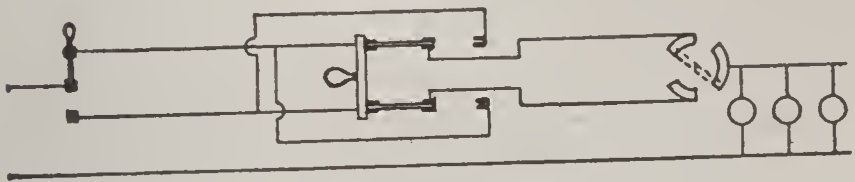


FIGURE 86.

By the system shown in Figure 87, a circuit can also be controlled from any number of places. The single-pole switches remain in the center and other

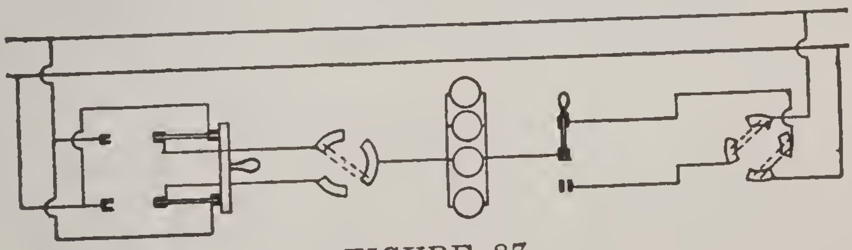


FIGURE 87.

switches are added as required. With this arrangement polarities may also be reversed in turning lamps on and off.

Figure 88 is known as an equal potential loop. This is useful on long lines where there is considerable loss; all lamps receive the same pressure and burn at the same candle-power.

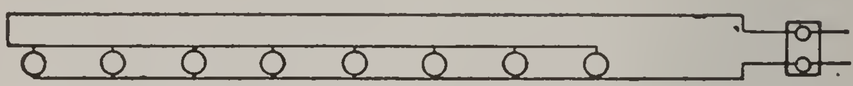


FIGURE 88.

Figure 89 shows a method by which lamps may be used at full candle-power; or, by throwing the switch over, they may be used at half candle-power, two in series.

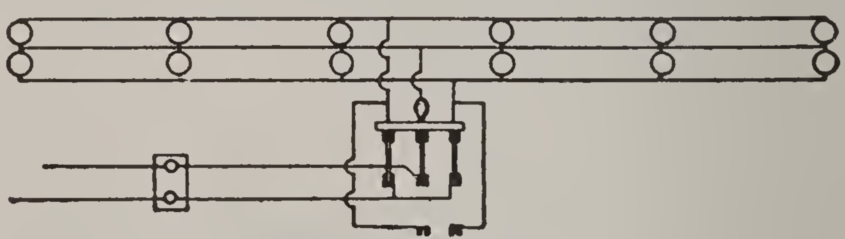


FIGURE 89.

Figure 90 shows one switch arranged to burn either two, four or six lamps. When connected at 1, the two top lights alone will burn; at 2 the four bot-

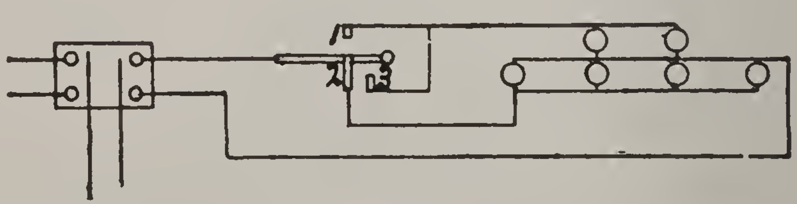


FIGURE 90.

tom lights will burn alone, while by connecting 2 and 3 all six lights will burn.

Figure 91 shows wiring arranged to provide a guest call for hotels or similar places. The bell 2 will ring and the lamp in series with it will burn only as long as the switch at the cutout remains closed. If the double-throw switch is thrown over, the bell 1 will

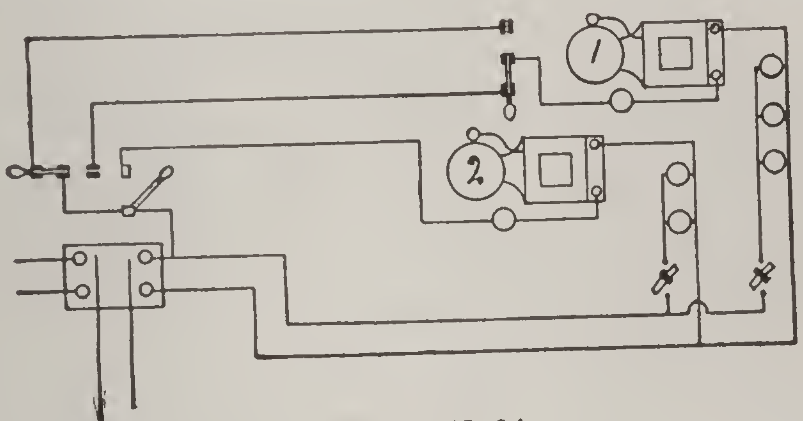


FIGURE 91.

continue to ring and the lamp will burn until the guest throws his switch over, or the party calling returns his to the original position.

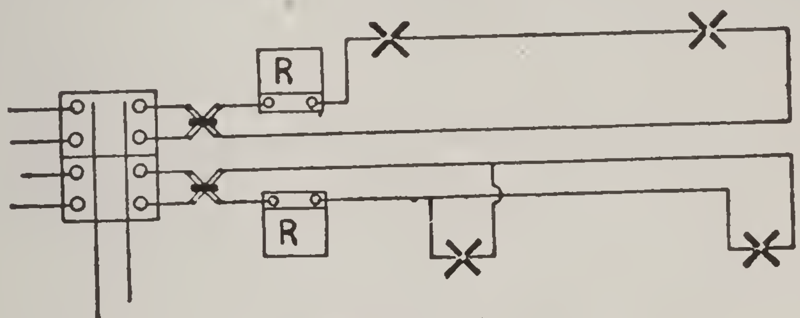


FIGURE 92.

In Figure 92 the wiring for low-tension arc lamps is shown. Such lamps may be wired either in series or in multiple, the wiring being arranged to suit the kind of lamps used. With all lamps of this kind some resistance must be used. With lamps run in

multiple it is usually provided with each lamp, and is generally built in with the lamp.

Figure 93 shows a throw-over switch so arranged that only one lamp at a time can be used, one resistance answering for both. All switches used in con-

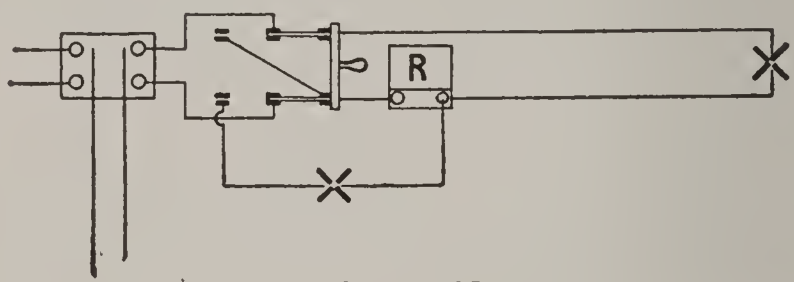


FIGURE 93.

nection with direct-current arc lamps must be arranged so that polarities cannot be changed by them.

Figure 94 shows connections enabling one to burn either the two lamps at the right or those at the left, only two at a time being used. This arrangement requires the use of series lamps.

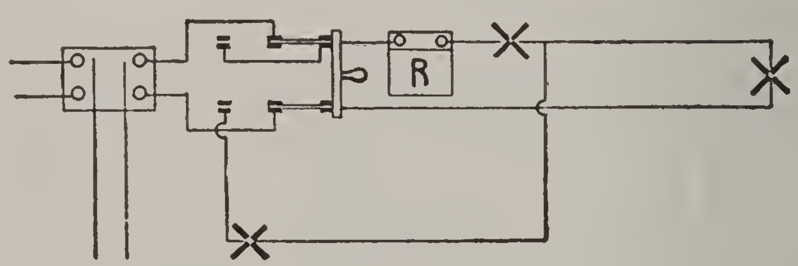


FIGURE 94.

Figure 95 shows a system of wiring which makes it possible to light all of the lamps in a building, not controlled by key sockets, from three different places at any time, even after they have been turned

off by the occupants of rooms. In the top part of the figure one double-throw switch and one three-way

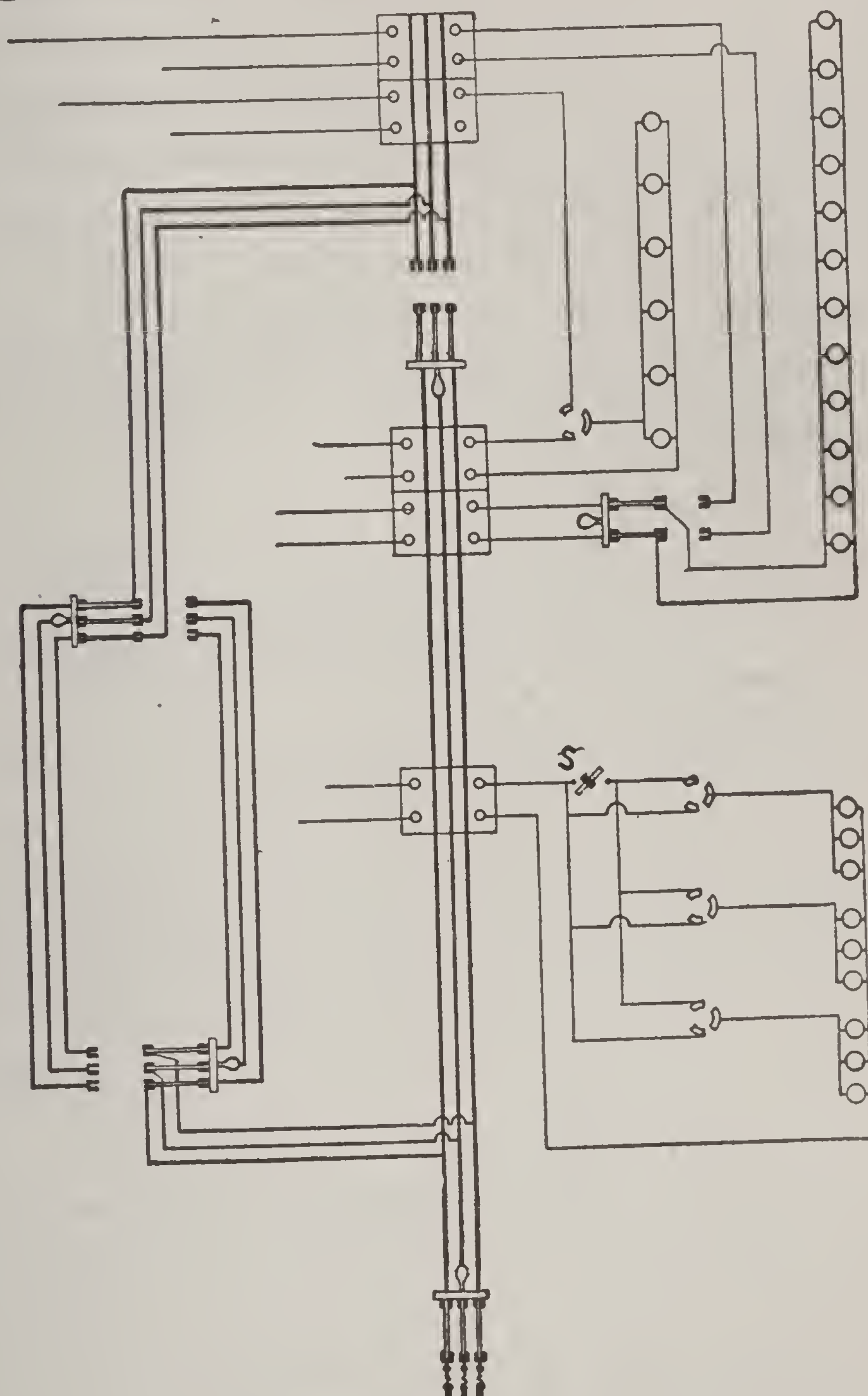


FIGURE 95.

snap switch are shown. Whenever, by either of these switches, the lamps are turned off, the switches

make connection with the cutouts above, so that by throwing any one of the three knife-switches the lamps may be lighted again. In the lower part of the figure one circuit is arranged for the same purpose. By closing the single-pole switch S, all of the lights may be turned on at any time, excepting, of course, those that are turned off at the sockets. This arrangement is very useful in case of fire, or any emergency where it is desired to illuminate a whole house quickly.

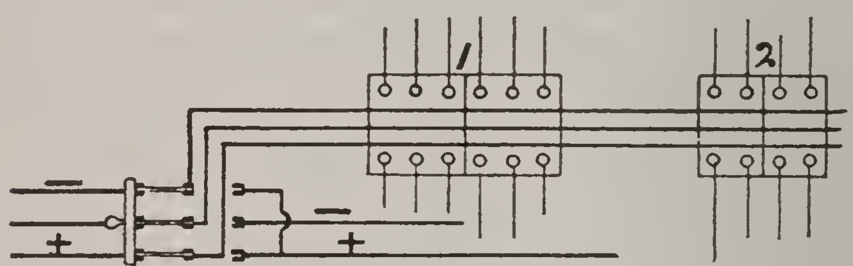


FIGURE 96.

Figure 96 shows the wiring of a convertible system. By means of the three-wire switch, connections may be made to either a two or three-wire supply. With this system the middle or neutral wire should have as much carrying capacity as both outside wires, since when used with a two-wire supply it must carry the full load, while either of the outside wires need carry but half the current. Cutouts of the kind shown in group 1 should not be used in connection with this system. They are not very objectionable in straight three-wire systems, but when used in connection with two-wire systems the middle fuse must be doubled to

carry the load. Such cutouts as are shown in group 2 are preferable. Great care is necessary when arc lamps are to be connected to such a system. They can be connected with one side of the neutral only, and this side must be arranged so that polarities are not reversed when the main switch is thrown over.

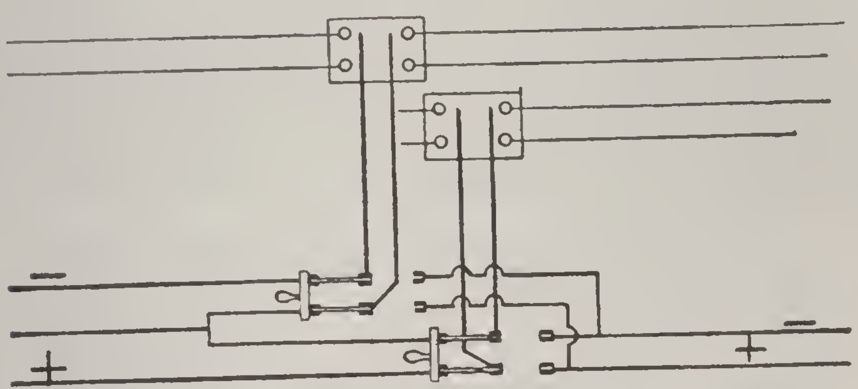


FIGURE 97.

Where arc lamps are used extensively and where it is necessary to balance the load, as on the Edison three-wire system, the wiring used in Fig. 97 may be employed. In place of the two double-pole, double-throw switches, a four-pole, double-throw switch may be used.

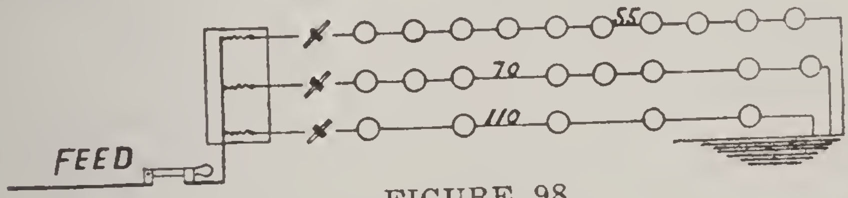


FIGURE 98.

Figure 98 shows incandescent lamps arranged in series. This plan of lighting is generally used in connection with street railway work. The figure shows 550 volt circuits provided with lamps of differ-

ent voltage. Instead of the ground a return wire may be used.

Figure 99 shows the wiring of a high-tension arc circuit. A group of incandescent lamps is also shown. When incandescent lamps are used in connection with arc lamps as shown there must be enough lamps in each group to take the current used by the arc lamps. The switch S controls the incandescent lamps and also the arc lamps 1, 2, 3 by simply short-circuiting them. The double-pole switch

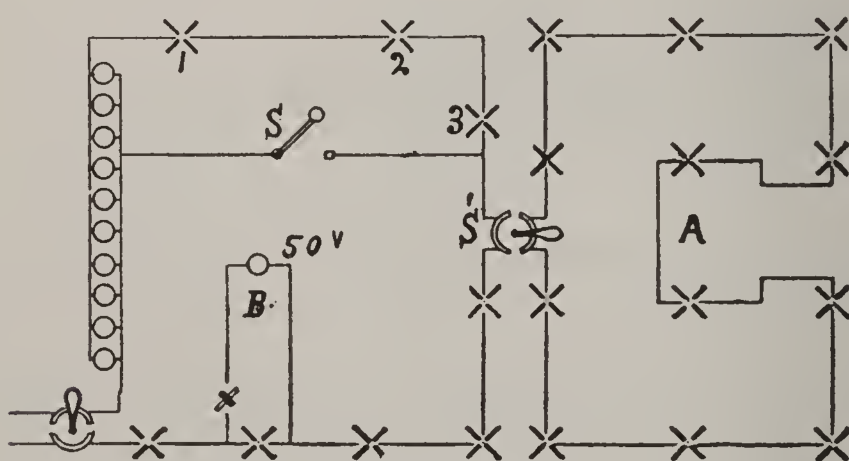


FIGURE 99.

S′ controls the group A and is so arranged that when turned off this group is entirely disconnected. This is the only safe way of switching high-tension arcs: where they are merely short-circuited they are nearly as unsafe to handle as when burning. At B one incandescent lamp is shown controlled by a single-pole switch. When this lamp is burning it robs the arc lamp of as much current as it requires, the amount of current depending on the candle-power of the

lamp. Incandescent lamps should be used on arc circuits only in an emergency and then only where there is little risk of fire.

Figure 100 shows a diagram of the connections of a theater switchboard. The board is fed by the two sets of mains shown by the arrows on the lower sets of bus bars. The lower set of bus bars feeds the lights in the house, or auditorium, switch 51 controlling the majority of these lights. A set of bus bars running from this switch feeds a number of smaller main switches which control all the lights in the different sections of the house, such as the gallery, balcony, main floor, etc. Bus bars running from these switches feed other switches which control the different groups of lights in the various sections of the house.

The other set of main bus bars at the bottom of the board feeds the lights on the stage, these lights being controlled by four main switches: 24, which controls all the white lights; 35, all the red lights, and 43, all the blue lights, smaller switches being used to control the different colored lights in the foots, borders, strips, etc.

The switches which operate the white lights, 17 to 23 and 26 to 32, are all double-throw, the upper contacts of which are connected to a set of bus bars controlled by the main white switch, 24, while the lower contacts are connected to a set of bus bars independent of this switch. By means of this arrangement

part of the lights can be thrown off by the main switch while certain ones are left burning.

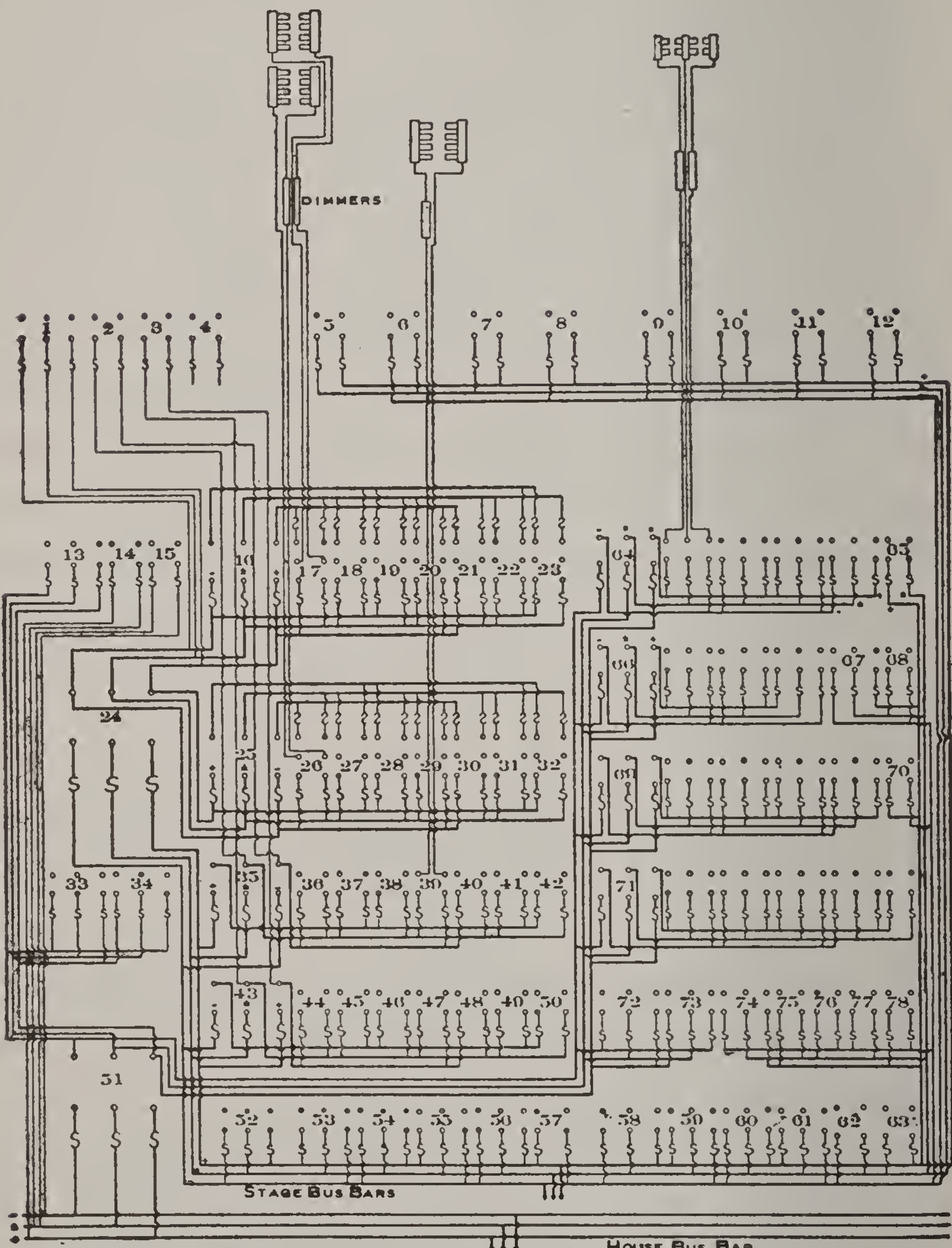


FIGURE 100.

A few of the circuits are shown connected to the dimmers from which they run to the branch circuit cutouts.

1. White Strips.
2. Red Strips.
3. Blue Strips.
4. Switchboard Lights. (Connected to House Bus Bar.)
5. Sub-basement Lights.
6. Basement Lights.
7. Basement Lights.
8. Paint Bridge Motor.
9. Patrol Lights.
10. Air Compressor Motor.
11. Exhaust Air Motor.
12. Exhaust Air Motor.
13. Sunlight Ceiling.
14. Orchestra Lights.
15. Program Lights.
16. Top White Main.
17. Top White Foots.
18. Top White Border, No. 1.
19. Top White Border, No. 2.
20. Top White Border, No. 3.
21. Top White Border, No. 4.
22. Top White Border, No. 5.
23. Top White Proscenium.
24. Main White Switch.
25. Bottom White Main.
26. Bottom White Foots.
27. Bottom White Border, No. 1.
28. Bottom White Border, No. 2.
29. Bottom White Border, No. 3.
30. Bottom White Border, No. 4.
31. Bottom White Border, No. 5.
32. Bottom White Proscenium.
33. Boxes.
34. Boxes.
35. Red Main.
36. Red Foots.
37. Red Border, No. 1.
38. Red Border, No. 2.
39. Red Border, No. 3.
40. Red Border, No. 4.
41. Red Border, No. 5.
42. Red Proscenium.
43. Blue Main.
44. Blue Foots.
45. Blue Border, No. 1.
46. Blue Border, No. 2.
47. Blue Border, No. 3.
48. Blue Border, No. 4.
49. Blue Border, No. 5.
50. Blue Proscenium.
51. Main House Switch.
52. Plug Pockets.
53. 35 ampere Pockets.
54. 35 ampere Pockets.
55. 35 ampere Pockets.
56. 100 ampere Pockets.
57. Curtain Motor.
58. 100 ampere Pockets.
59. Dressing Rooms.
60. 100 ampere Pockets.
61. 200 ampere Pockets.
62. Picture Machine.
63. Picture Machine.
64. Fifth Floor and Gallery.
65. Fans.
66. 4th Floor.
67. Stage Chandelier.
68. Fans.
69. Third Floor.
70. Hoist Motor.
71. First and Second Floors.
72. Balcony Front.
73. Balcony Front.
74. Paint Bridge.
75. Rigging Loft.
76. Fly Floor.
77. Fly Floor.
78. Pump Motor.

Figure 101 shows a diagram of the connections of an elevator signalling device. The diagram is shown for only six floors, but it is evident that it could be extended to any number of floors. At each floor, with the exception of the top and bottom, are two incandescent lamps, the upper lamps (shown by light circles) burn when the elevator car is moving upward, while the lower lamps (shown by black circles)

burn when the car is traveling downward. These lamps are connected to a series of contacts, *2*, *3*, *1′*, *2′*, etc., which are mounted on a device generally located at the top of the shaft near the elevator machine. A sliding contact, which is operated by means of a screw geared to the elevator drum and so designed that the motion of the elevator car from the top to the bottom of the shaft will move the contact piece over the entire length of bar *a*, makes connection between the contacts *a* and *2*, *3*, *4*, *5*, *6*, while the car is moving upward, and between *a′* and *1′*, *2′*, *3′*, *4′*, *5′*, while the car is moving downward. This movable contact is of such size that connection is made to three or four of the contacts, *2*, *3*, *4*, etc., at one time. The operation is as follows: Suppose the car is at the bottom of the shaft. The sliding contact piece will connect *a* with contacts *2*, *3* and *4*. Current will then flow from the Main to the "up" lamps on the 2d, 3d and 4th floors. As the car moves upward contact is made to points, *3*, *4* and *5*, while the contact to the 2d floor is broken. In this way the lamps on three or four floors ahead of the car will

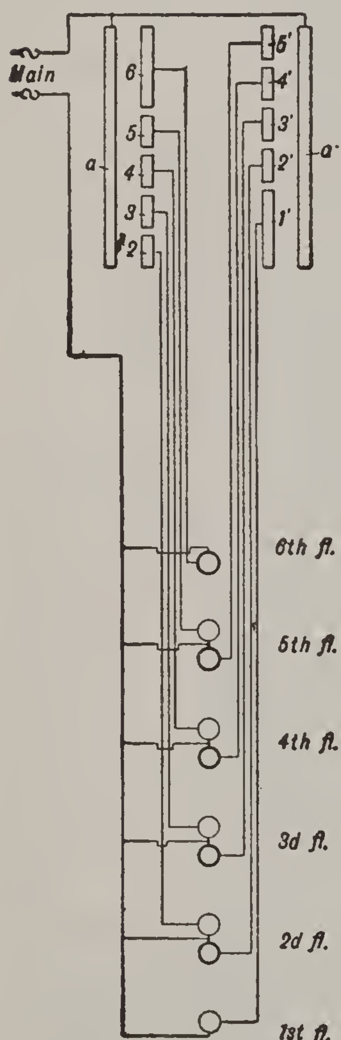


FIGURE 101.

burn until the car reaches the top of the shaft. The last contact, *6*, is of such size that it will take in the whole movable contact so that while the car is at the top of the shaft the light on the 6th floor only will burn and this light shows that the car is going down. When the car starts to move downward the connection between *a* and *6* is broken and connection made between *a′* and *5′*, *4′* and *3′*, the "down" lamps on the corresponding floors then burning. As the car moves downward the operation previously explained will be repeated except that the "down" lamps will burn.

CHAPTER X.

ARC LAMPS, NERNST LAMP, COOPER HEWITT LAMP.

Figure 102 shows the circuits of the improved Brush arc lamp. This lamp is used on constant-current, direct-current systems. The current enters the

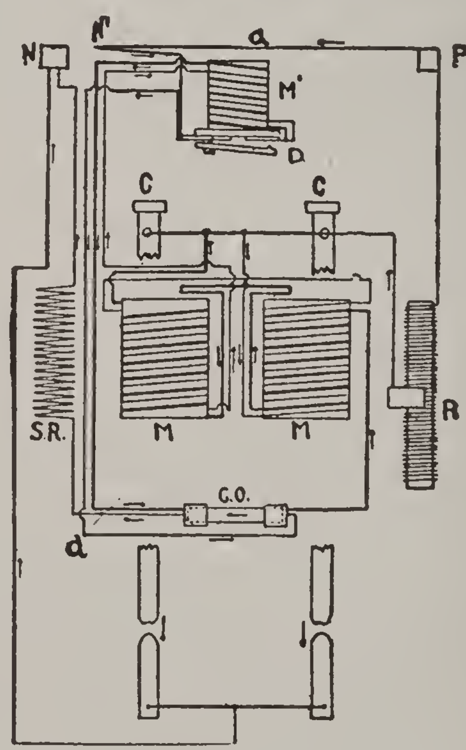


FIGURE 102.

positive binding post P and part of it goes through the resistance R to the carbon rods C, C, then through the carbons to the negative post N. The remainder of the current passes through wire *a* to the cutout block **C, O,** but, as the cutout is closed at first, the current

crosses over through the cutout bar to the starting resistance S, R, and to the negative side of the lamp; a part of this current, however, is shunted at the cutout block through the coarse wire winding of the magnets M, M, and so to the upper carbon rod and carbons and out. The fine wire winding of the magnets M, M, is connected in the opposite direction to the coarse winding, and its attraction is therefore opposite. When the arc increases in length, its resistance increases, and consequently the current in the fine wire is increased. The attraction of the coarse wire winding is therefore partly overcome and the armature begins to fall. As it falls the arc is shortened and the current in the fine wire decreases. The fine wire of the magnets M, M, is connected in series with the winding of the auxiliary magnet M′. This magnet, which also has a supplementary coarse winding, does not raise its armature unless the voltage at the arc increases to 70 volts. The two windings connect at the inside terminal on the lower side of the auxiliary cutout magnet and the current from the fine wire of the main magnets passes through both windings and then to the cutout block and so to the starting resistance and out. If the main current is interrupted (as by the breaking of the carbons) the whole current of the lamp passes through the fine wire circuit. This will energize the auxiliary magnet M′ and close a circuit directly across the lamp through the coarse wire on M′ to the main cutout

and thence to negative terminal. When the main cut-out C, O, operates, the armature of the auxiliary cut-out falls because there is not sufficient current in that circuit to energize the magnet. This lamp is switched off by simply short circuiting it across N, N′.

In all direct current arc lamps care must be taken to see that the current enters at the proper binding post, as the positive carbon burns away about twice as fast as the negative carbon. When a lamp is burning a small cup-shaped formation will be noticed at the arc on the positive carbon and a small projection on the negative carbon. Lamps are generally connected so that the upper carbon is positive, and this hollow formation on the positive will throw the light downward. In this way it can be determined by the way the light is thrown as to whether a lamp is burning right side up or not.

Figure 103 shows the circuits in a constant current arc lamp for use on alternating current systems. When the lamp is switched on current passes through the coarse winding of magnet M and then to the carbon rod and carbons and out at the other terminal. This energizes M and attracts the core A, thus raising the upper carbon and establishing the arc. The magnet M′ is wound with a great length of fine wire and opposes magnet M. As the resistance of the arc increases more current is sent around the fine wire winding of M′ and the core A and the carbon thus lowered. If for any reason (breaking of the car-

bons, etc.), the resistance at the arc is greatly increased, the core A will be lowered until the two points of the cutout C come in contact when the main current will pass through C and resistance R to the post T′. The resistance of R is in such proportion to M′ that just enough current is sent around M′ to keep the cutout C closed. By means of the spring S the length of the arc may be adjusted. Tightening the spring increases the arc by requiring a greater amount of current to flow around M′ to lower the carbons.

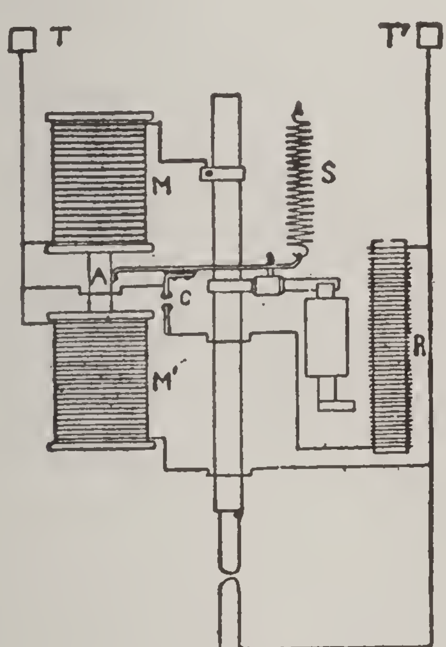


FIGURE 103.

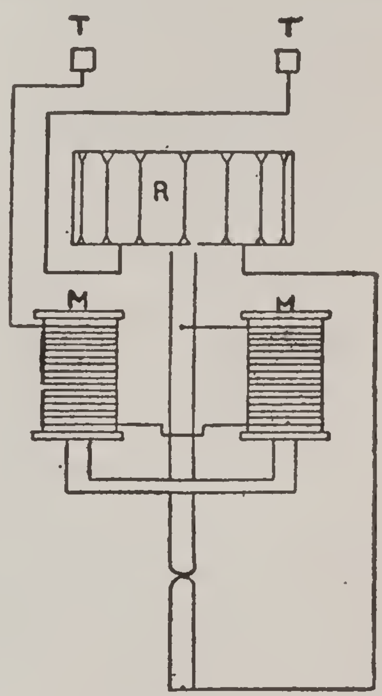


FIGURE 104.

Figure 104 shows the winding of a constant potential, alternating current arc lamp. R is a reactance or choking coil, the purpose of which is to cut down the voltage of the line to that required by the arc. This coil takes the place of the resistance coil in the

direct current, constant potential lamp. The current passes from the binding post T to the magnets M, M, and then to the upper carbon, from there to the lower carbon and then through the reactance coil and out at the other terminal. It will be noticed that this lamp has no shunt winding similar to the constant current lamp. This is unnecessary as the voltage at the terminals is practically constant. As the carbons burn away the current through M, M, is decreased, due to the increased resistance of the arc, and the armature is lowered, thus lowering the carbons.

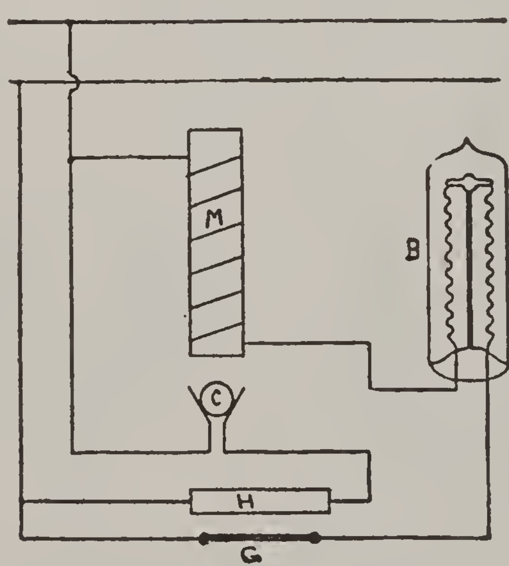


FIGURE 105.

Direct-current, constant-potential arc lamps differ from the constant-current lamps in that no automatic cutouts can be used, and in order to put out the lamp, the circuit must be opened. Constant-current lamps require no extra resistance, while con-

stant-potential lamps cannot be operated without some resistance to steady the current.

Figure 105 shows the diagram of a Nernst lamp. In the diagram, H is the heater, which is made up of a winding of platinum wire on a porcelain tube. The glower G is composed of an oxide which at the ordinary temperature is of very high resistance but when heated lowers in resistance considerably. The ballast B is made up of fine iron wire which increases in resistance as it becomes heated, thus tending to steady the current and keep the voltage over the glower as near constant as possible. When the lamp is started current passes through the heater H, gradually heating it and the glower, which is located directly below it. As the glower is heated current begins to pass through it and the cutout magnet M, until finally it becomes strong enough to attract the cutout C which opens the heater circuit. This circuit will then remain open as long as current is passing through the glower. These lamps are made in several sizes from one to six glower and they consume when burning 88 watts per glower. Each glower is equal in candle-power to three ordinary 16 candle-power incandescent lamps. When the lamp is started more current is used than when the lamp is burning, owing to the fact that the heater coils are in circuit. In the six-glower lamp which takes when burning 2.4 amperes on 220 volts, the starting current rises to about 3.2 amperes. These lamps are at present used only on alternating current

systems as the glower becomes blackened in a short time when used on direct-current systems.

Figure 106 shows a diagram of the connections of the Cooper Hewitt mercury vapor lamp. The

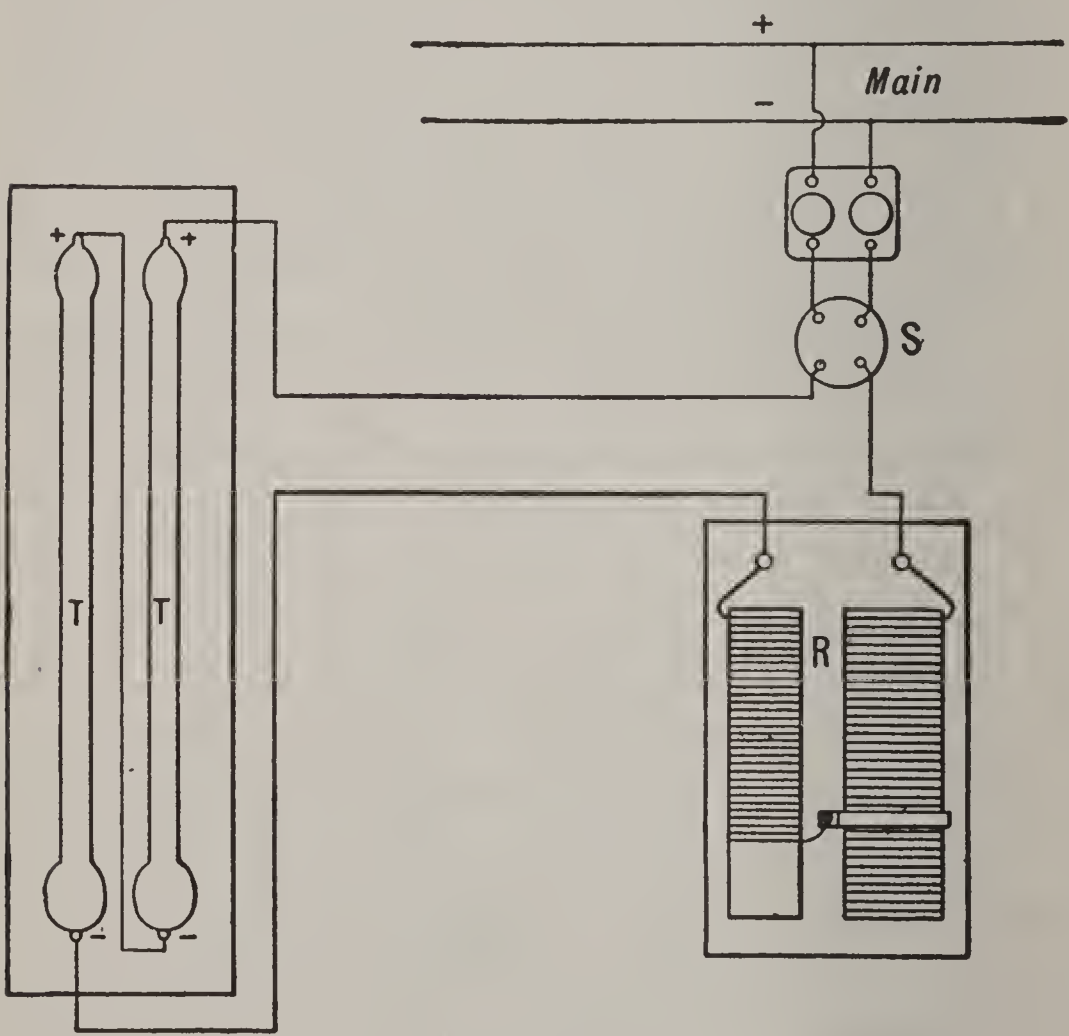


FIGURE 106.

light from this lamp is emitted from the two tubes T, T′, which, when current is passing through them, glow with a greenish light. The tubes T, T′, are of glass and the air has been extracted from them; they are provided at their upper ends with electrodes inside

the tube to which leading in wires are attached and at the lower ends with iron cups which are partially filled with mercury. Either of two different methods are used to start the lamp. In one case a coil of great inductance is used to send a kick of current through the tube between the positive and negative electrodes, thus breaking down the high resistance and allowing current to flow. In the other method after the current is turned on the tubes are tipped until all the mercury in the lower cup flows out into the tube and forms a path to the upper electrode. As the tube is tipped back and the column of mercury leaves the upper electrode light is given off. The connections can be easily traced. Current passing from the positive main flows through the cutout, switch S, to the positive terminal of tube T′ then through tube T′ to the negative terminal and out to the + of tube T, through this tube and the adjustable resistance R to the negative side of the line. The two tubes and the resistance are simply connected in series through the proper cutout and switch. Great care must be taken to see that current flows through the lamp in the proper direction for, if current is sent through in the wrong direction, even for a few minutes, the tube will be ruined. The type of lamp shown is used for photographic purposes and takes about 3.5 amperes at 110 volts when running normally. At the start the current rises to a little over 100% for a very short time. The ordinary lamp consisting of a single tube

is rated at about 750 C. P. After the lamps have been in use for some time (about 1600 hours), the inside of the lamp becomes coated with a brownish substance and small globules of mercury will adhere to the sides. The tubes then have to be replaced. For photographic purposes this lamp taking 3.5 amperes compares very favorably with a 10 ampere arc lamp.

CHAPTER XI.

RECORDING WATTMETERS.

Figure 107 shows the circuits in the two-wire Thomson recording wattmeter. One of the mains is connected through the winding M, M, which forms the fields of a motor. The armature of this motor is connected across the mains in series with a resistance R and the shunt field S. This shunt field is always in circuit, whether there is current used through the meter or not, and it is so arranged that it tends to start the motor. Its purpose is to overcome the friction of the armature so that the meter will register on very small loads. It will be noticed that the connection for the potential circuit is taken off the main at A. This is done so that the meter will register the current used in the potential circuit, and this is one reason why the generator must always be connected on the left side and the load on the right side of the meter. If this form of meter is fed from the wrong side it will run backward. In Figure 107 it will be seen that if the feed were reversed (leaving polarities unchanged) the current through the fields would be in the opposite direction, while that through the armature would remain unchanged, hence the motor would be reversed. Used on direct-current this meter runs as a simple

direct current motor and when used on alternating current, at each reversal of the current the polarities of both the fields and armature are changed simultaneously; and the motor will therefore continue to run in the one direction, because changing the direction of current in both the fields and armature of a shunt motor does not change the direction of rotation. There is no iron used in the construction of the motor and therefore no loss from heating.

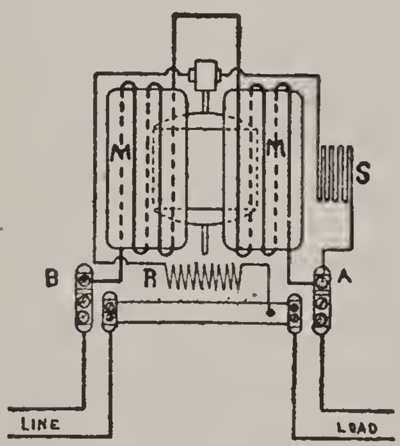


FIGURE 107.

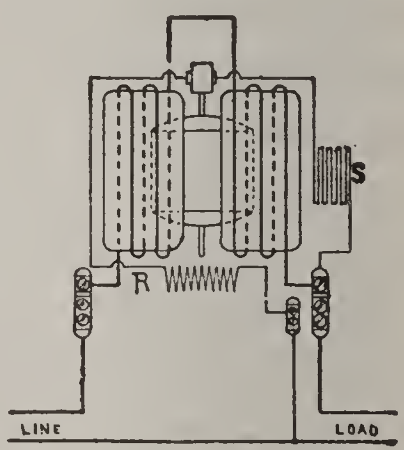


FIGURE 108.

Figure 108 shows the two-wire meter for heavy loads. The circuits in this meter vary from the preceding one only in having but one main carried through the meter with a tap to the other main.

Figure 109 shows the three-wire meter. The two outside wires (positive and negative) are carried through the meter, one through each field, and the armature is connected from one outside to the neutral. In some of the three-wire meters no neutral tap is

used, the potential circuit being connected directly across the outside mains.

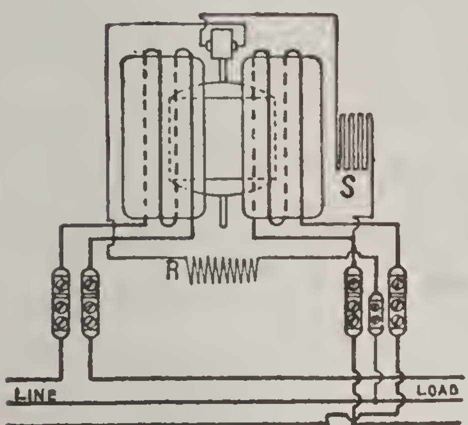


FIGURE 109.

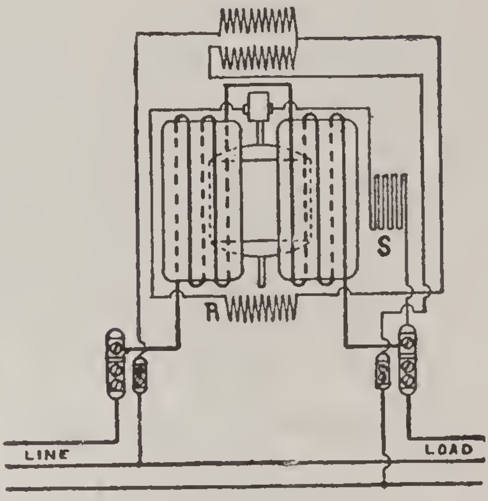


FIGURE 110.

Figure 110 shows a meter for a balanced three phase line.

Figure 111 shows a station meter for use on series arc lines.

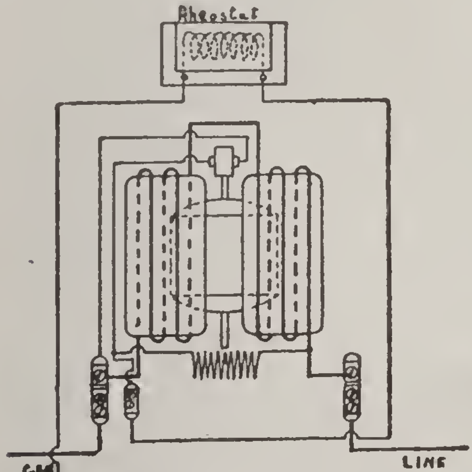


FIGURE 111.

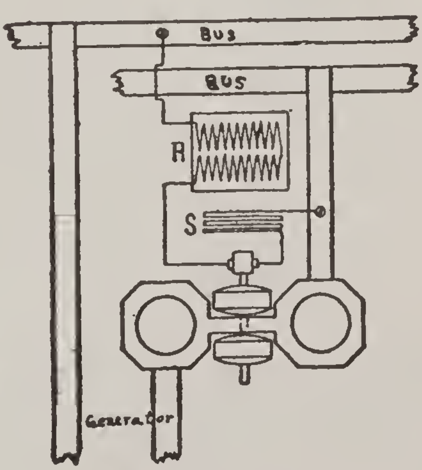


FIGURE 112.

Figure 112 shows a meter used on switchboards to record the entire current passing through the bus bars.

Figure 113 shows the circuits in the Gutmann wattmeter. This meter is used with alternating currents only and depends for its action on an aluminum disk, slotted in spiral lines, operated in joint action with a shunt laminated magnet coil S′ and a pair of series coils S, S. In the two-wire meter the series coils are connected in series with one of the mains and the shunt coil is connected across the mains as shown in diagram. The loss in the shunt coil does not exceed 1½ watts on the 110 volt 60 cycle meter and the drop in the series coil does not exceed ¼ of one volt on full load on the small size meters, and is proportionally less in the larger meters.

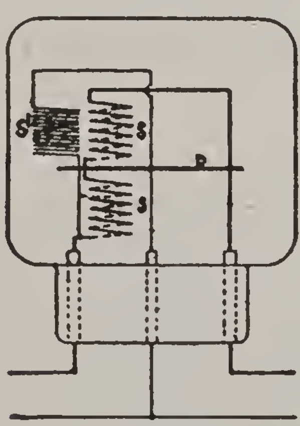


FIGURE 113.

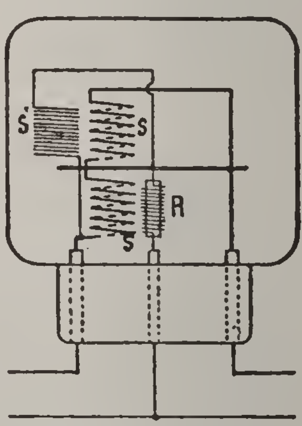


FIGURE 114.

Figure 114 shows the 200-250 volt meter. This meter has in series with the shunt coil a reactance coil R.

Figure 115 shows the three wire meter. In this meter one of the outside mains is carried through one series coil and the other through the other series

coil. No tap is taken to the neutral as the pressure circuit is connected across the mains as in the 200-250 volt meter.

Figure 116 shows a meter for use on either 100 or 200 volt systems. The connection shown in the full lines is for 100 volts and the dotted for 200 volts. The reactance coil R is balanced to have exactly the same choke as the shunt coil.

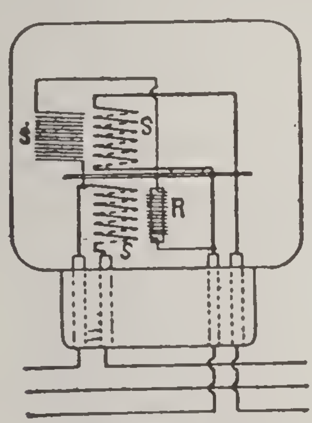


FIGURE 115.

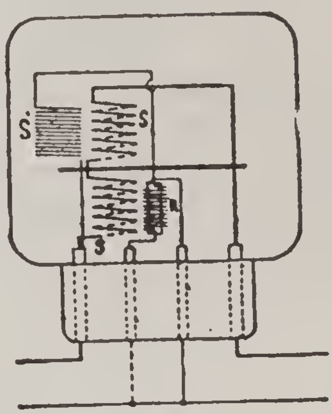


FIGURE 116.

In Figure 117 the connections of an Edison chemical, three-wire meter are shown. The two outsides only are carried through the meter, no neutral connection being used. This type of meter was one of the first used on commercial work, the amount of current having passed through the meter in a given time being determined by the amount of zinc deposited on the negative electrode. These meters are rapidly being replaced by the mechanical meters.

Figure 118 shows a diagram of what is known as the Wright discount or demand meter. This meter is used in connection with recording wattmeters to de-

termine the maximum current which has been used during a given time. It is also used on circuits where it is desired to know the maximum current which has passed through the circuit. In the diagram, B is a glass bulb connected to a tube U which is partly filled with a liquid. Around bulb B is wound a resistance wire which carries the main current. When current is flowing in this wire heat is generated and the air in the bulb is expanded thus forcing the liquid around

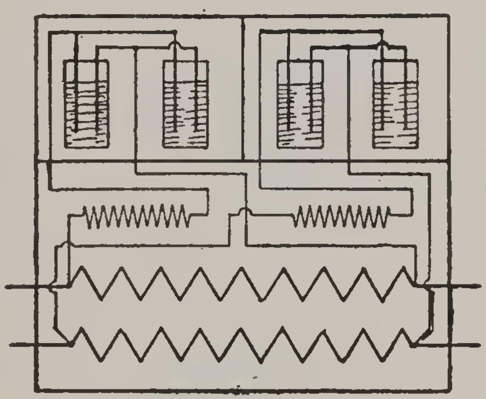


FIGURE 117.

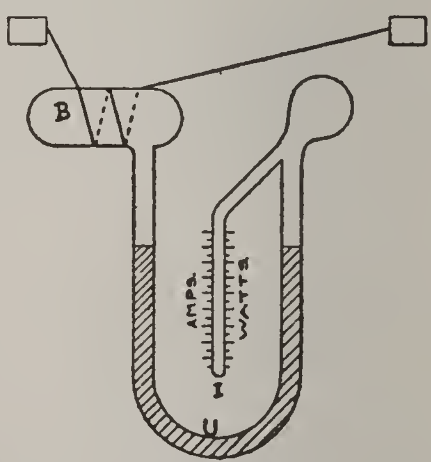


FIGURE 118.

tube U until it reaches the point where the tube U and I join, when it will flow into tube I. The amount of liquid in tube I will depend on the maximum amount of current which has passed through the resistance wire on bulb B. The scale back of tube I is graduated in amperes and watts. The meter is not effected by momentary increases in the current. If the maximum current lasts five minutes 80% will register; ten minutes, 95% will register; thirty minutes, 100% will register.

The Wright demand indicators described in the previous figure, 118, are influenced only by the current and therefore cannot be used on a. c. circuits having a power factor less than unity. The demand in all a. c. circuits must be measured in watts and therefore several types of demand meters have been de-

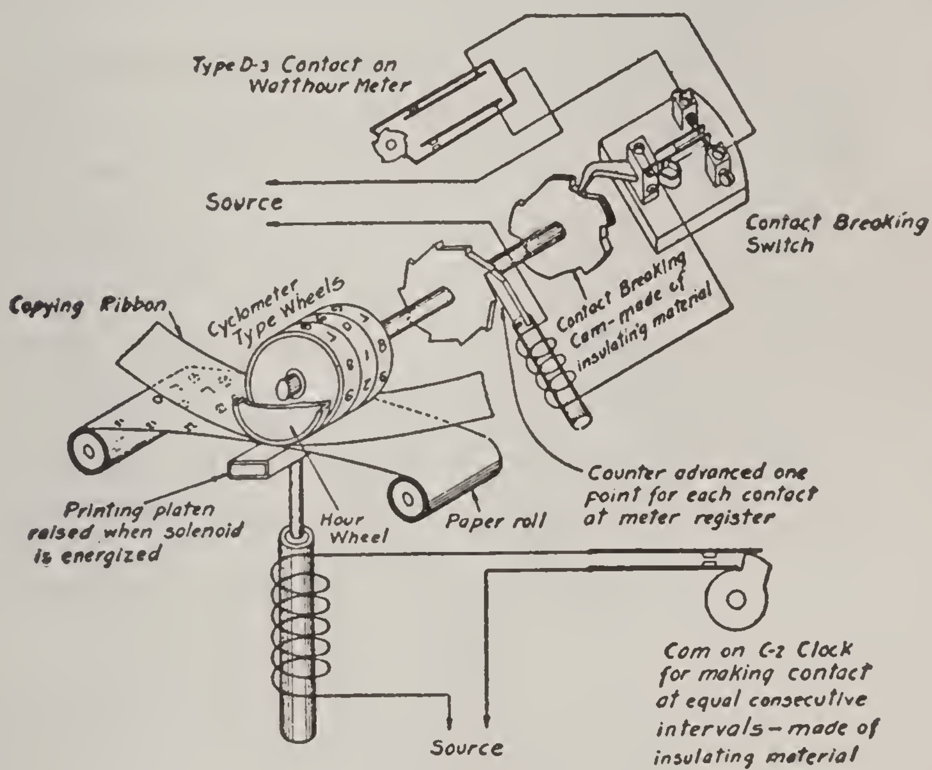


FIGURE 118a.

veloped which are governed directly by the watt meters in circuit. A diagrammatic sketch of one of these is shown in Figure 118 a. This instrument is manufactured by the General Electric Co. and is known as type P or "Printometer." A ratchet wheel made of insulating material is mounted on one of the spindles of the register as indicated in center at top of figure. Two blued steel spring brushes rest diamet-

rically opposite on the ratchet, thus allowing first one and then the other brush to drop off of the ratchet, at equal intervals. A platinum-iridium point is staked in each of these brushes, and as the brush falls off of the ratchet tooth, this point makes contact with another platinum-iridium point which is carried by a second spring-leaf running parallel to the brush. The two brushes resting on the ratchet wheel are charged all of the time with line potential. Thus, when these drop alternately upon the two leaves which connect to the cyclometer coil, we obtain the usual two-way circuit and alternately close the circuit through the cyclometer solenoid. Each time this solenoid is energized it advances the counters one point. A special contact-breaking switch is provided as shown in upper right hand corner and its object is to open the circuit immediately after the solenoid has moved the ratchet shown in center.

This type of demand meter is always accompanied with a clock which is arranged to print the record at certain intervals, usually 30 minutes. This is effected by means of the solenoid and electric circuit shown at bottom of figure. When properly set up and adjusted this instrument will print at predetermined intervals a record of the number of watts consumed in the meter circuits during that interval and the hour of the day at which the energy was used.

Another instrument devised for the same purpose and made by the General Electric Co. is illustrated

in Figure 118b. This instrument does not print a record but indicates the maximum amount of power used during a predetermined interval by means of a pointer. The registering device consists of a train

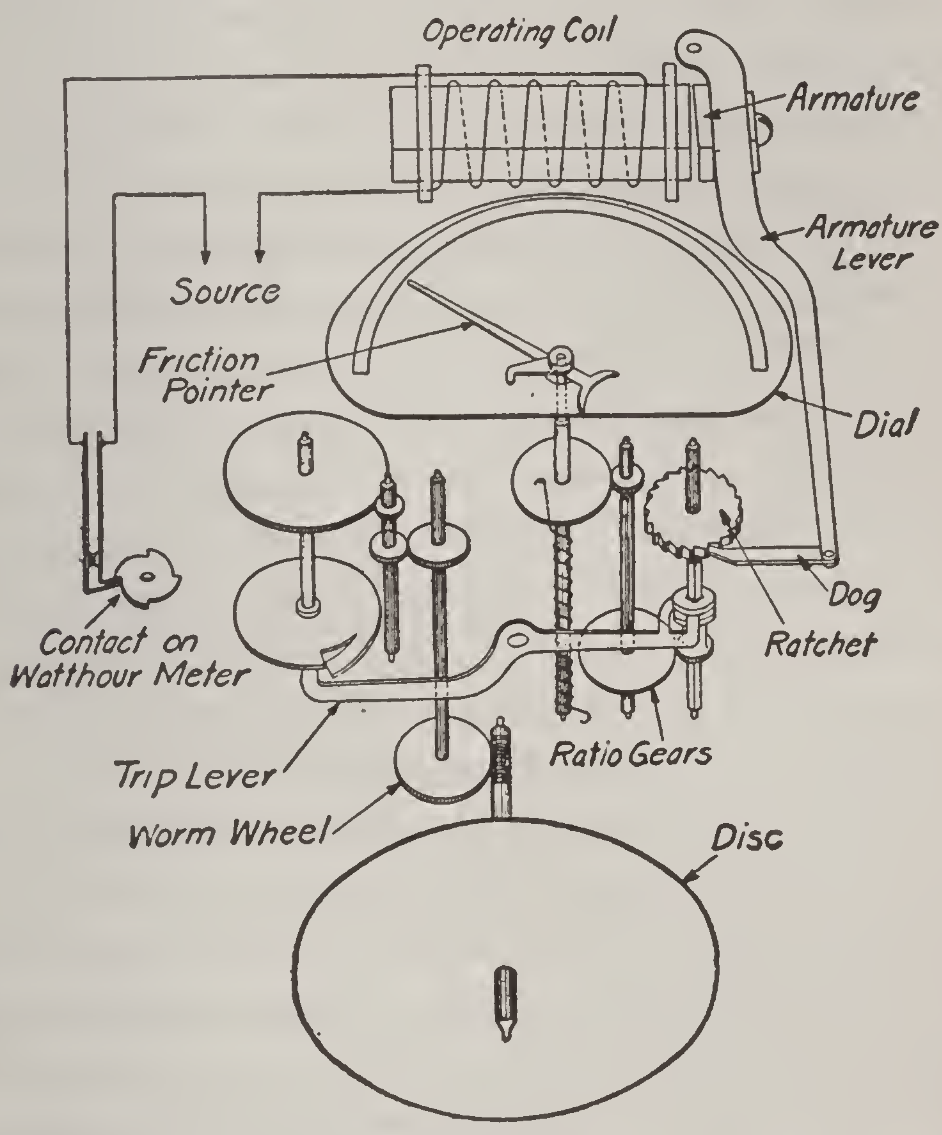


FIGURE 118b.

of gears arranged to drive the pointer forward over a semi-circular dial. The gear wheels are actuated by a ratchet and pawl mechanism which is driven by an electromagnet. This electromagnet is energized

once every time a certain number of kilowatt-hours of electrical energy have been registered by the watt-hour meter. It is evident, therefore, that the position of the dial pointer of this demand meter is directly dependent upon energy consumption as registered by the watthour meter.

Since the demand meter gives the demand for a definite time interval, it is necessary that the mechanism which drives the dial pointer forward over the scale shall be reset to zero position at the end of the time interval, but shall leave the dial pointer at the most advanced point on the dial scale to which it has been carried. This resetting of the register mechanism to zero is accomplished by a mechanism governed by a constant speed device so that the resettings are accurately timed. When used in connection with a.c. circuits the device is operated by a small constant speed motor. For d.c., clock work is used.

The above instruments are usually set to make complete records of loads that last for some time. If the load during that time is fairly constant, they may be considered as giving the true instantaneous maximum load. If the actual instantaneous value of current or wattage is wanted, some form of chart-drawing instrument is usually inserted in the circuit. If none such is at hand a curve representing with pretty fair accuracy the fluctuations in the circuit may be obtained in the following manner, which has been successfully employed by the authors: Take an ordinary

sheet of paper and write upon it in straight lines the numbers, 1, 2, 3, etc. Let each of these numbers stand for seconds and let there be as many as will cover the time during which observations are to be taken. Let one man observe the disk of wattmeter and be prepared to give some signal each time the disk completes one revolution. Let another man hold a watch and count off the seconds as the watch ticks them off. A third man must now be prepared to follow with a pencil the numbers on the paper in the order as the watch holder reads off the seconds. With a little practice the man in charge of the paper will soon learn to follow along in synchronism with the time indicated by the watch, and at every signal from the disk reader, make a mark upon the paper. With a few minutes' practice three men will learn to co-operate very nicely in this way. The rate at which energy is consumed in the circuit will be inversely proportional to the time required for the disk to make one revolution. If the load carries with it some sudden high peaks, the disk reader may let two revolutions of the disk occur before giving the signal, but he should then have some distinctive signal for the marker so that he will understand and mark accordingly.

CHAPTER XII.

DIRECT CURRENT MOTORS.

Figure 119 shows the winding of a series motor for use on constant-potential circuits. In this motor the fields and armature are in series across the main circuit. The purpose of the starting box SB is to insert a resistance in series with the armature when

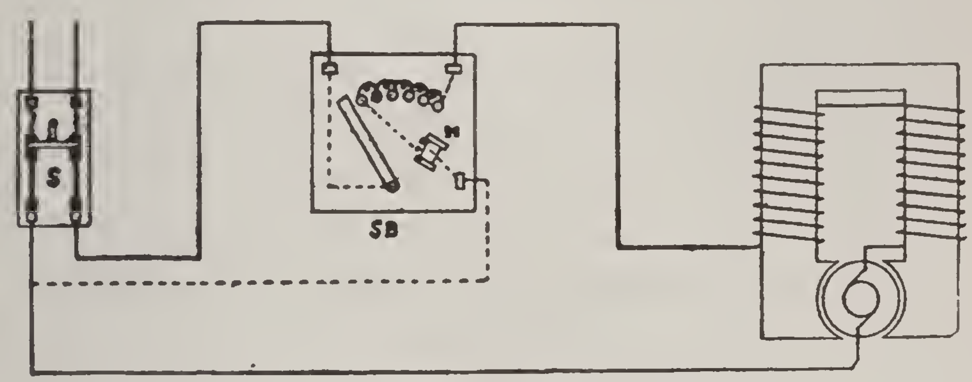


FIGURE 119.

starting, to prevent an excessive flow of current which would result were the main current thrown on fully with the armature at rest. To start the motor the main switch S is closed, and the arm of the starting box is moved gradually from one contact to another until it has reached the position where no resistance is left in circuit. It is then held by means of the small magnet M in this position until the current is cut off, or for some reason ceases to flow, when, by means

of a spring attached to it, the arm will fly back to its original position. This makes it impossible to throw the current on while all the resistance is out of the armature circuit. The small magnet M is connected directly across the mains, generally having a resistance in series with it to reduce the voltage on the winding. This resistance is placed in the starting box, and is not shown in the drawing. In some motors the automatic coil M is connected in series with the main current, but in this case the variations in the current from no load to full load make its use unsatisfactory.

The speed of a series motor varies with the load, decreasing as the load increases and vice versa. If the load is entirely removed the motor will run away, unless, as in the case of very small motors, the ohmic resistance of the field and armature is sufficient to control it. This type of motor is also used on street car work, although in this case the starting box is replaced with a controller which, by varying the resistance or connecting the motors in series or multiple (where two motors are used), varies the speed. [See Figure 127.] Reversing either the field or armature connections will reverse the direction of rotation. If the field and armature are both reversed the motor will run in the same direction.

This motor is always protected from overload by a fuse or circuit-breaker placed in the main circuit. Fuses are shown in the drawing on the motor switch.

Figure 120 shows the winding of a shunt motor. The field and armature of this motor are placed in shunt across the main circuit. The starting box SB is placed in the armature circuit and performs the same service as in the constant-potential, series motor. The automatic coil of the starting box is connected in series with the field circuit. The speed of a shunt motor is practically constant, and for this reason this type of motor is extensively used. The motor is

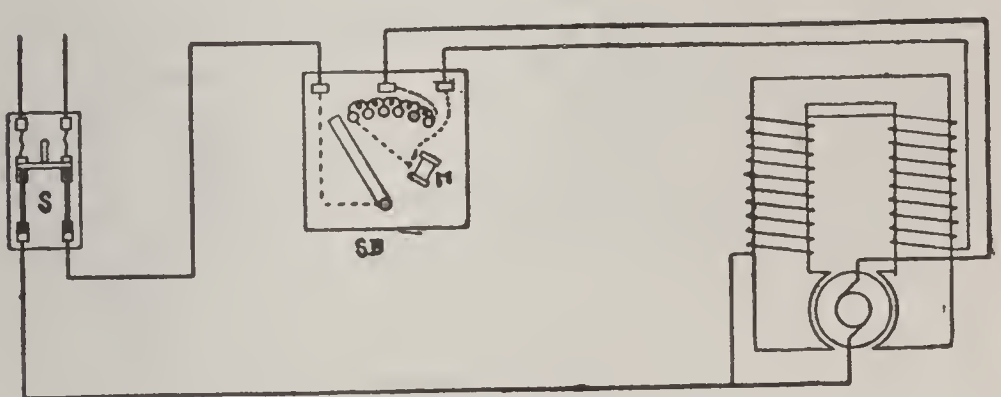


FIGURE 120.

started in the same way as the series motor, and is protected from overload in the same way. If either the field or armature connections are reversed the motor will run in the opposite direction. The speed of a shunt motor may be varied by inserting resistance in either the armature or field circuit [See Figure 124], or by shifting the brushes.

It must also be remembered that the loss in the line in long runs feeding a motor will cut down the P. D. at the armature, and this will decrease the speed

as the load increases. To obviate this the size of wire should be chosen so that the drop in potential shall be as small as possible.

Figure 121 shows the winding of a compound motor. In addition to the shunt winding on the fields an extra winding is added, which is in series with the armature. The starting box is connected in series with the armature, and the automatic coil M is connected in series with the shunt field as in the shunt

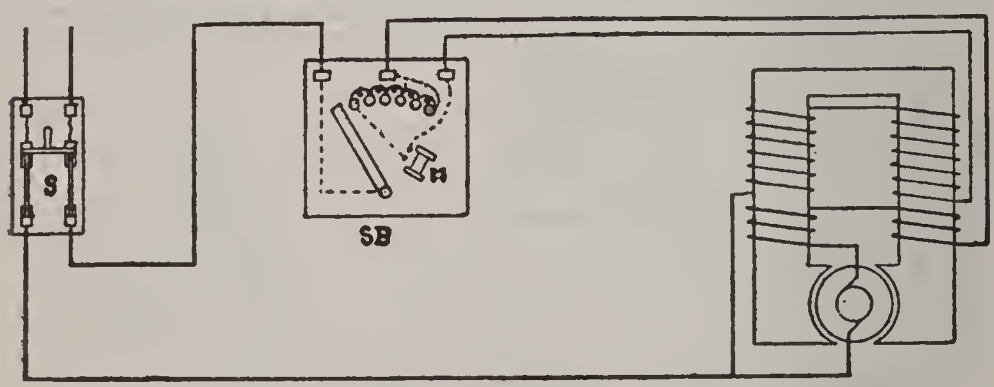


FIGURE 121.

motor. The series winding of these motors is connected in either of two ways, known as the "cumulative" or "differential." The winding shown in the diagram is cumulative, the current in the shunt and series winding being in the same direction. In the differential winding the current in the series coil travels in an opposite direction from that in the shunt coil.

Motors having the differential winding will maintain a more constant speed; for, as the load increases,

the increased current in the series winding will partly neutralize the effect of the shunt winding and decrease the magnetism of the field, thus tending to increase the speed of the motor. On loads which have a constant variation, such as the planer, for instance, when, at the end of each stroke a great increase of load comes on, the differential motor is apt to spark badly. The cumulative motor will in the same case slightly decrease in speed at each stroke. The differential motor is not as efficient as the cumulative form from the fact that there is a waste of current due to the two fields opposing each other.

Where motors are used in isolated plants the motor switches should be opened before the plant is shut down.

A number of different connections by which the speed of a motor may be varied or the direction of rotation reversed, are shown in Figure 122. Where the three-wire system is in use the speed of a motor may be varied by using the three-wire, double-throw switch shown at the left of the diagram. With the switch thrown to the upper position the armature will obtain the full line voltage, and with the switch on the lower position the armature will receive the voltage between the outside and the neutral; while the field will receive in both cases the full voltage of the line. In the 110-220 volt system the upper connection gives 220 volts and the lower connection 110 volts on the armature, the field receiving 220 volts. It is cus-

tomary to use a three-wire, single-throw switch to connect the service to the motor, this switch being

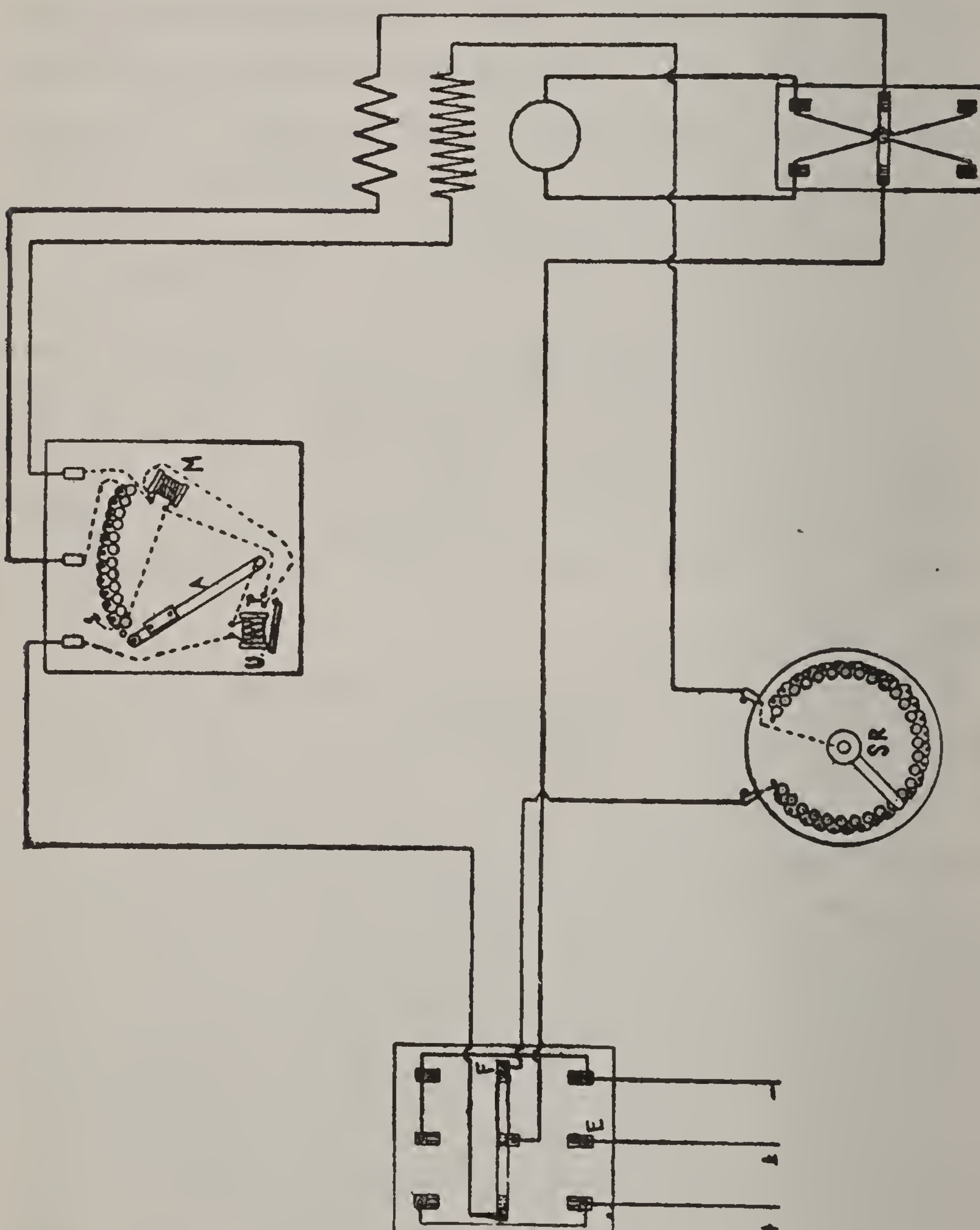


FIGURE 122.

placed in the line before the double-throw switch and being used whenever it is desired to shut down the

motor. The double-throw switch is only operated when the motor is at rest.

In the upper part of the diagram are shown the connections of the Cutler-Hammer underload and overload starting box. With the movable arm A on contact shown in drawing no current will flow. If the arm is moved to contact 1 current will flow from the main through magnet U to the arm A, through all the resistance to the series field and armature and to the other side of the line. As soon as the movable arm has made contact with 1, current will also flow through the winding of magnet M and out to the shunt field and opposite side of line. The arm A is gradually moved to the right until it reaches the last contact, where all the resistance is cut out of the armature circuit. When it reaches this point the magnet M, which is energized, attracts the armature on the arm A and holds it in this position as long as current is flowing through the magnet.

If the main supply were for any reason shut off, the magnet M would be de-energized, and the arm A (which is equipped with a spring) would fly back to the "off" position. This makes it impossible for the supply current to be momentarily cut off and then thrown on again while all the resistance is cut out of the armature circuit. In case the field circuit should open, by the breaking of a wire, for instance, the magnet M would be de-energized and the current cut off. When the motor is shut down by opening the

motor switch, the arm A will not fly back until the speed of the motor has considerably decreased, owing to the fact that the motor is acting as a generator and sending current around the shunt field and coil M.

The purpose of the magnet U is to protect the motor from any excessive rise in current, due either to a short circuit in the motor or to the throwing on of too heavy a load. With the normal current flowing through the winding of U, the armature below it will not be attracted; but if the current exceeds a certain amount the armature is attracted, and the winding of the automatic magnet M short-circuited at the point P, thus demagnetizing M and allowing the arm A to fly back and shut off the current from the motor. The armature below magnet U is adjustable, so that it may be set to operate at whatever current is desired.

Similar apparatus to the above may be used to regulate the speed of the motor by applying resistance in series with the armature, and thus cutting down the current; but in such case the apparatus is designed to carry the full current for an indefinite time. The automatic coil M is arranged to attract an armature which is connected to a pivoted lever, having a point at the other end which fits into a series of indentations on the lower part of arm A, and holds the arm squarely over the contacts in whatever position it may be placed for the required speed.

Strengthening the field of a motor tends to decrease

the speed, and weakening the field to increase the speed. SR is a rheostat connected in series with the shunt field by means of which more or less resistance may be cut in series with the fields. Cutting in more resistance will reduce the current in the fields, and thus weaken them and increase the speed, and cutting out resistance will act in the opposite way.

The two-pole, double throw switch shown in lower right-hand corner may be used to reverse the direction of rotation of the armature. With the switch thrown to the upper contacts the current will enter the armature from the right-hand side, and with the switch thrown to the lower contacts current will enter on the left-hand side of the armature, thus reversing the direction of rotation. This switch should never be thrown while the motor is running, but should be thrown over while the armature is at rest.

Figure 123 shows connections for the Cutler-Hammer printing-press controller, as used with a shunt motor. R is a resistance box generally in the larger size motors installed separately from the controller, and connected to it by wire leads. The automatic coil M is connected in series with the field circuit, and when current is on attracts an armature (not shown in drawing) which is connected to a pivoted lever, the other end of which fits into a series of indentations on the lower end of the arm A and holds the arm in whatever position it may be placed. The arm A is made in two pieces, separated by an insulator so that

the upper and lower parts are not in electrical connection. As the arm is moved to point 1, current from the mains enters the lower part of the arm and goes to the copper segment S. From there it is carried to the armature and back to the segment T. It

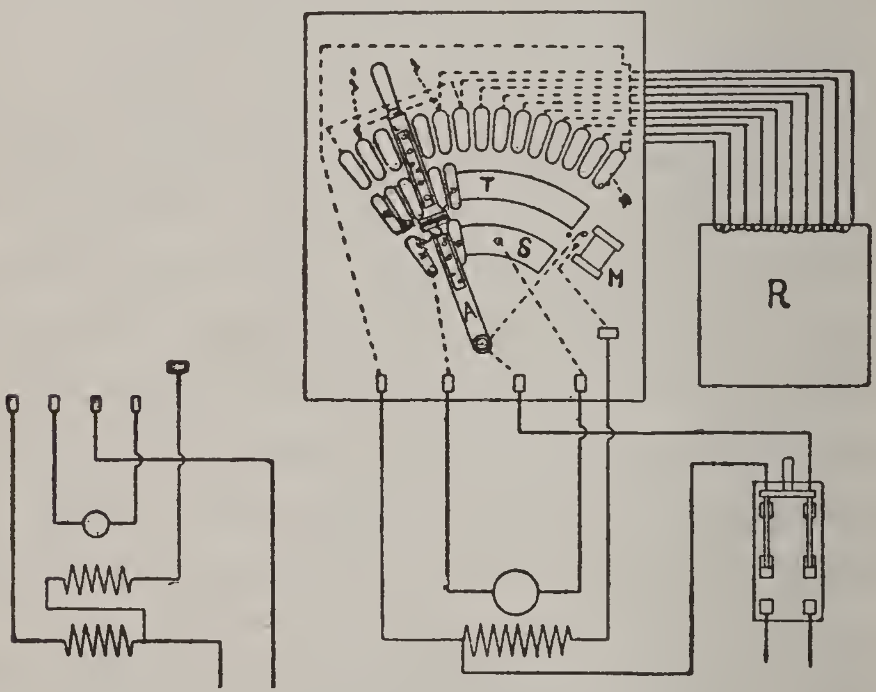


FIGURE 123.

then crosses the upper part of the arm to the contact 1 and through all the resistance in R and back to point 10 to the other side of the line. The field is simply connected across the mains through coil M. If the arm A is moved to point 1, the current will then flow through the armature in the opposite direction, thus reversing the direction of rotation. With the arm on contact 10 all the resistance is cut out of the armature circuit. This controller has ten variations in speed forward, and two backward. At the

left is shown a diagram of the connections of this starting box when used with a compound motor.

In Figure 124 are shown connections for the Cutler-Hammer self-starter used with a motor driven pump. The connections shown are for a compound motor.

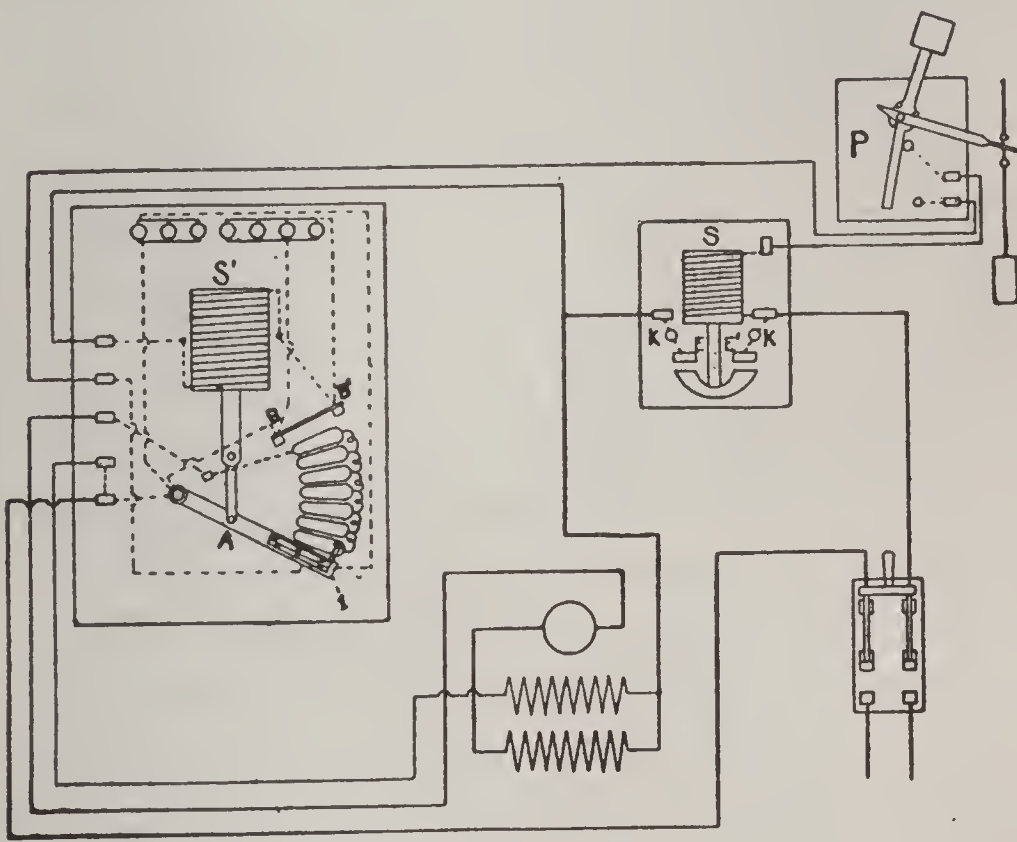


FIGURE 124.

S is a solenoid connected across the mains through the switch P and the arm A of the self-starter. The current in this circuit varies from ¼ to 1 ampere, according to the size motor used. The switch P is controlled by a float in the tank, and is so arranged that it will close as the level of the water lowers and open again when the tank has become filled. This

switch may be placed any distance from the motor. When the switch P closes, the solenoid S is energized, and the core, at the lower end of which is attached a copper contact piece, closes the contacts E, E′, thus allowing current to flow through the series field and armature of the motor and through all the resistance in the starter. At the same time, when E E′ is closed current passes through the solenoid S′ and through the small spring connecting contacts B B′. This energizes the solenoid S′ and draws up the core and arm A, thus gradually cutting resistance out of the armature circuit. When the arm reaches the upper contact, the circuit through the solenoid S′ is opened at B and the lamps thrown in series with it. This is done to cut down the current flowing through the solenoid, as less current is required to keep the arm in place than to move it over the contacts. The circuit from the small solenoid S is connected to the contact 1 so that when the arm A moves upward lamps are thrown in series with this circuit, to cut down the current in the solenoid S to that required to just hold it; so that, if for any reason the supply current is cut off, the contact E E′ cannot be closed until the arm A has moved to the lower point, where all the resistance is in the armature circuit. The number of lamps used varies with the size of motor. This same apparatus can be used with any air pump, or elevator in which the motor does not reverse, the switch P being replaced with the necessary switch.

On the solenoid S the small magnets K are used to extinguish the arc at the break.

Figure 125 shows a diagram of the connections of a shunt motor used for blowing a pipe organ. The arm of the resistance box R is mechanically connected to the bellows of the pipe organ so that its position is determined by the amount of air in the bellows. When all of the air is out of the bellows the arm of

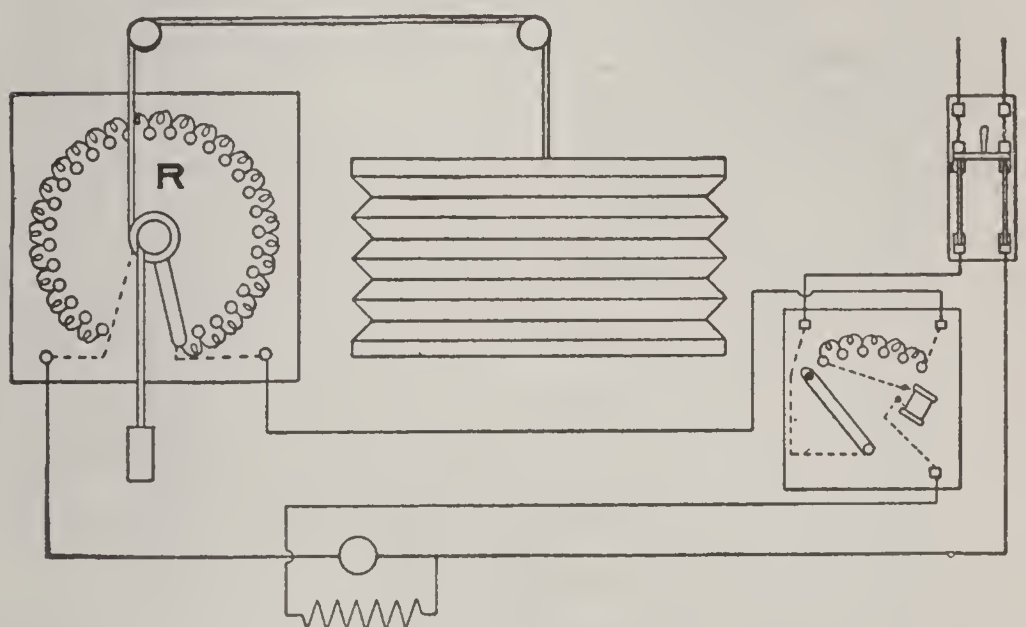


FIGURE 125.

the rheostat is in the position where no resistance is in circuit, or as shown in the diagram. As the motor speeds up and air is forced into the bellows the rheostat arm slowly moves over the series of contacts cutting resistance into the circuit at each step. When the bellows are completely filled the arm is on the last contact where all of the resistance of the box R is in series with the motor, this resistance being great

enough to completely stop it. From the above description it will be seen that the action is automatic, the speed of the motor being governed by the amount of air taken by the organ. After the organ has been at rest for some time the air gradually leaks out of the bellows and the rheostat arm moves to the point where no resistance is in circuit. For this reason a starting box is always provided.

Figure 126 shows the connections of the Cutler-Hammer compound drum controller, this type of controller being used on printing presses, cranes and other work requiring a frequent change in speed and direction of rotation. In the upper part of the diagram is shown the drum laid out, the contact rings X, Y, Z, Y′, Z′ and W, and the segments below being mounted on a revolving drum, while the contacts 1 to 7 and B, A, SF, B′ A′, SF′ and L are stationary, being supplied with fingers which make contact with the segments opposite as the drum is revolved.

With the drum moved to the first point on the forward motion the rings X, Y, Z will come in contact with A, SF and 1 respectively, and the rings W, Y′ Z′ with B′, SF′ and L. Current will then flow from the + main through the series field to the resistance box R and through all the resistance to the point 1 of the controller. From 1 it passes to contact ring Z, and then through ring X and contact A to the armature and back to B′ and ring W to ring Z′ and contact L to the negative side of the line. As the drum is moved

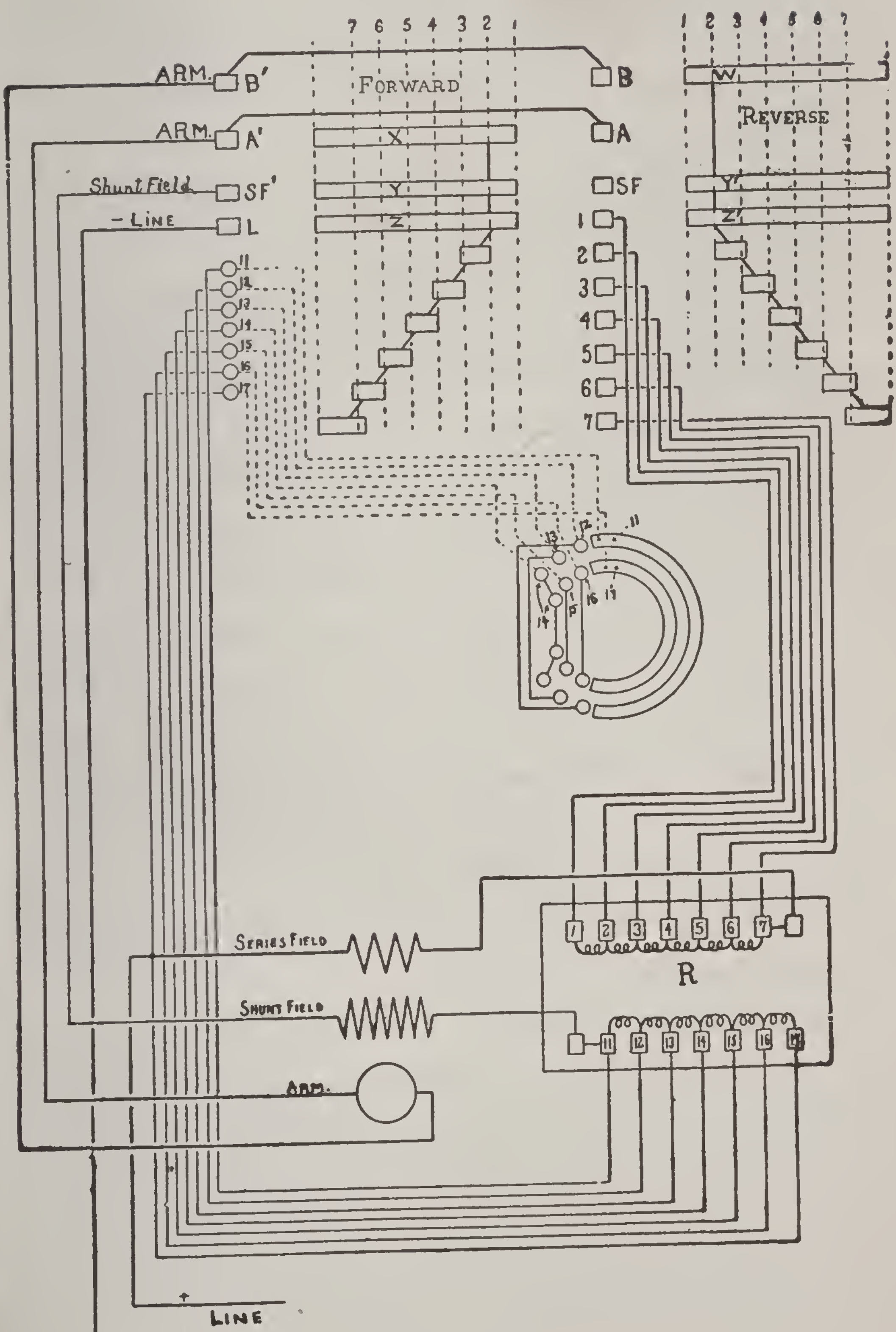

FORWARD
REVERSE
ARM.
B'
B
A'
A
Shunt Field
SF'
SF
- LINE
L
X
Y
Z
W
Y'
Z'
SERIES FIELD
SHUNT FIELD
ARM.
R
+
LINE
-

FIGURE 126.

toward point 7 at each step, part of the resistance in series with the armature is cut out, until at 7 the armature and series field are connected directly across the mains.

In the bottom of the controller are located two copper rings and a number of contacts, which are connected to their respective points in resistance box R. A small, movable contact shoe short-circuits rings 11 and 17, while the controller is moved from points 1 to 7, thus allowing current to pass from the positive side of the line to 17, on to 11, and then through the shunt field and out to bar Y′ on controller and to negative side of line. As the drum passes point 7 the contact shoe connecting 17 and 11 will then connect 17 and 12, thus cutting the resistance between points 11 and 12 in the resistance box R in series with the field and increasing the speed of the motor. As the controller is moved still further, more resistance is cut in series with the field, until at point 14 all the resistance is cut in and the motor has reached its highest speed.

If the drum is moved to 1 on the reverse motion the same connections are made with the exception of the armature. In this case current from contact 1 passes to ring Z′ and then to B and armature, this causing current to flow in the opposite direction in armature and reversing the direction of rotation. In printing press work a stop is used which allows the

reverse motion to take in two contacts only, thus limiting the reverse to two speeds.

Figure 127 shows the connections of the General Electric K2 street car controller. This controller is of the series parallel type, and varies the speed of the

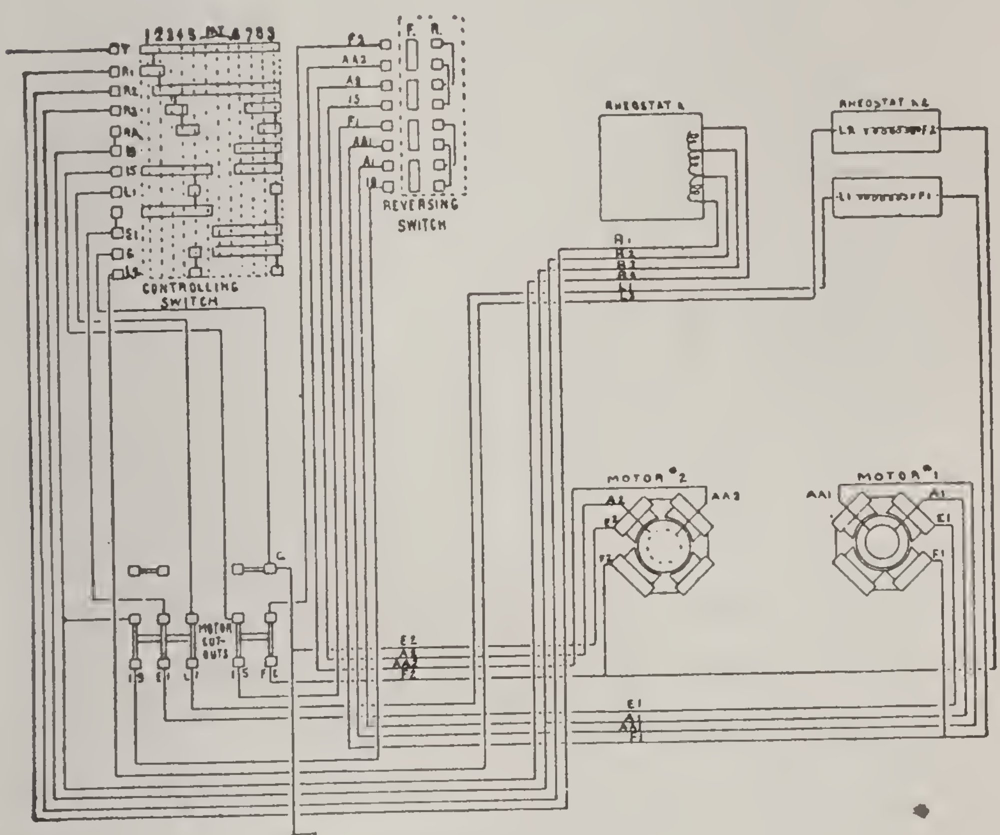


FIGURE 127.

car by connecting the motors first in series and then in parallel, suitable resistance being used to give a gradual starting current. In Figure 128 are shown the various connections between the rheostat and motors obtained at the different points of the controller. In the upper left-hand corner the drum of the controller is laid out. T, R1, R2, etc., are stationary

contacts with fingers which make contact with the various segments on the drum as it is revolved.

At the right of the controller is the reversing switch, by means of which the car can be made to go in either direction. The reverse switch is also a drum on which are placed two sets of contacts, these making connection with the stationary points F2, AA2, etc., as the drum is revolved. If the controller drum is moved to point 1, the current from the trolley wire enters at T, then to segment on drum opposite T. From there it passes to contact R1, then to rheostat K, through all the resistance to the point 19 on the reverse switch. With the reversing switch on F it will then pass to A1, through the armature of motor No. 1 back to AA1, on the reverse switch and through field of motor No. 1 to the point E1 on the controller. From E1 it passes to the point 15 by means of segments on the drum, and to 15 on the reversing switch and to armature of motor No. 2 back to AA2 on the reversing switch, and to the field of motor No. 2 and back by means of E2 to the ground. The two motors are now connected in series with all the resistance in rheostat K in series with them. This is shown in 1 of Figure 128.

As the controller is moved to points 2 and 3, part of the resistance in rheostat K is cut out, until at 4 the two motors are running in series with no resistance. At point 5 the fields of both motors are weakened by shunting them around the resistance in rheo-

stat K2, thus further increasing the speed. The points between 5 and 6 are used to change the connections from series to multiple. At point 6 the motors are in multiple, in series with part of the resistance in K. At points 7 and 8 part of this resistance is cut out, while at 9 the motors are connected in multiple with the fields weakened.

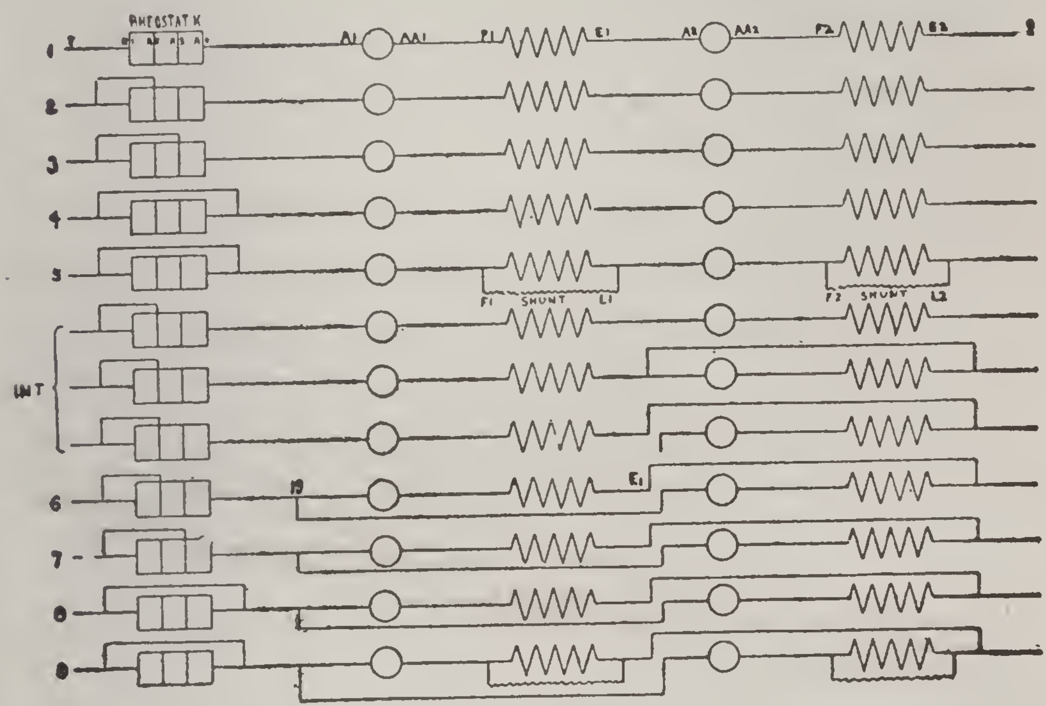


FIGURE 128.

In case it is necessary to cut out one of the motors, this may be done by means of the switches shown below the controller. If the switch at the left-hand is thrown to the upper contacts, motor No. 1 will be short-circuited. Throwing the other switch up short circuits motor No. 2. When one of the motors is cut out, a stop comes into play which allows the controller

to move over the first five points only. If this were not done and the controller moved to point 6, the trolley would be directly connected to ground through the rheostat K. This can be seen by reference to 6 in Figure 128, where cutting out motor No. 1 short-circuits 19 and E1. The car should never be run with the resistance in rheostat K in circuit, therefore points 4, 5, 8 and 9 only should be used for any great length of time. The diagram shows one set of controlling apparatus only, this set being duplicated at the other end of the car.

The speed of a constant current series motor varies with the load, decreasing as the load becomes greater and increasing in speed as the load becomes lighter. If the load is entirely removed the motor will "run away." No satisfactory method of winding has been devised which would make these motors self-regulating, so that if the motor is to be used on a varying load some mechanical device must be employed to regulate the speed.

In Figure 129 the arm A moves over a series of contacts which are connected to different points of the field winding. This arm may either be moved by hand, or, as is more common, connected to a centrifugal governor. As the load on the motor increases, its speed will slightly decrease, thus decreasing the speed of the governor and moving the arm upward. This cuts out part of the field winding and speeds up the motor.

In Figure 130 the arm A moves over a number of contacts which are in connection with the resistance

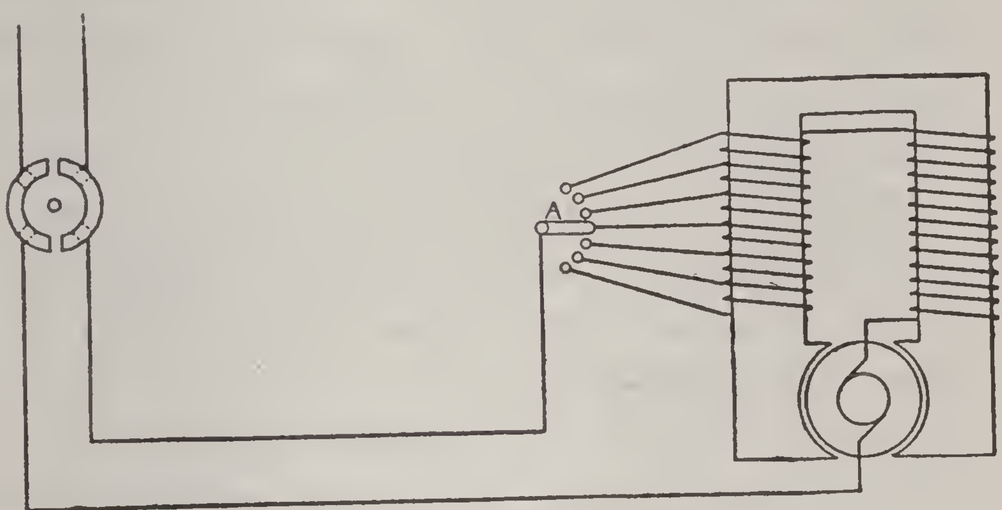


FIGURE 129.

wire R. Current coming from the left-hand main passes through the lower part of the resistance R and is shunted at the arm A, part of it passing

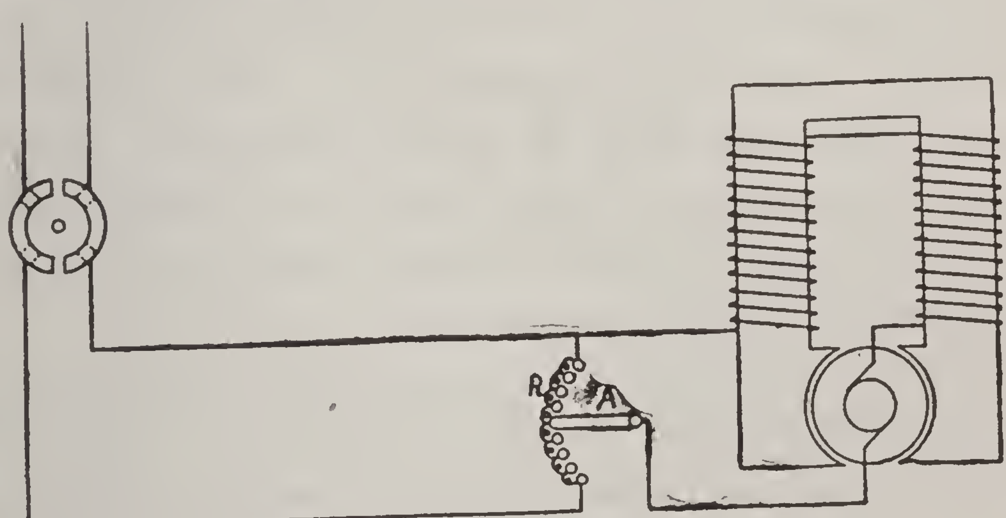


FIGURE 130.

through the remaining resistance and part of it going to the motor. By changing the position of the arm,

more or less current can be sent through the motor, the greatest amount passing through it when the arm is at the lowest contact. The arm may either be moved by hand or used with a centrifugal governor, as described in the preceding paragraph. It will be seen that this method is not very efficient, as a great deal of energy is consumed in the resistance wire. There are a number of other methods used for constant current series motor regulation, but they are mostly variations of those shown.

This type of motor is fast being replaced by the constant potential motor. Fuses are never used on these motors, as the current is always the same, and the switch used to start and stop the motor closes the main line when it opens the motor circuit. The ordinary snap switch cannot be used.

Figure 130a shows diagram of a printing press controller generally known as of the Kohler system and built by the Cutler Hammer Co. This system is widely used and there are many variations; modifications being made in some cases to fit different voltages and also to obtain different results as not all presses are run in the same way.

In the diagram M is the main magnet which when energized closes the armature circuit at A. The two circles below A represent blow out magnets which are not always used. The circuit can readily be traced along the heavy lines and through the rheostat R. N is another magnet or solenoid which when energized

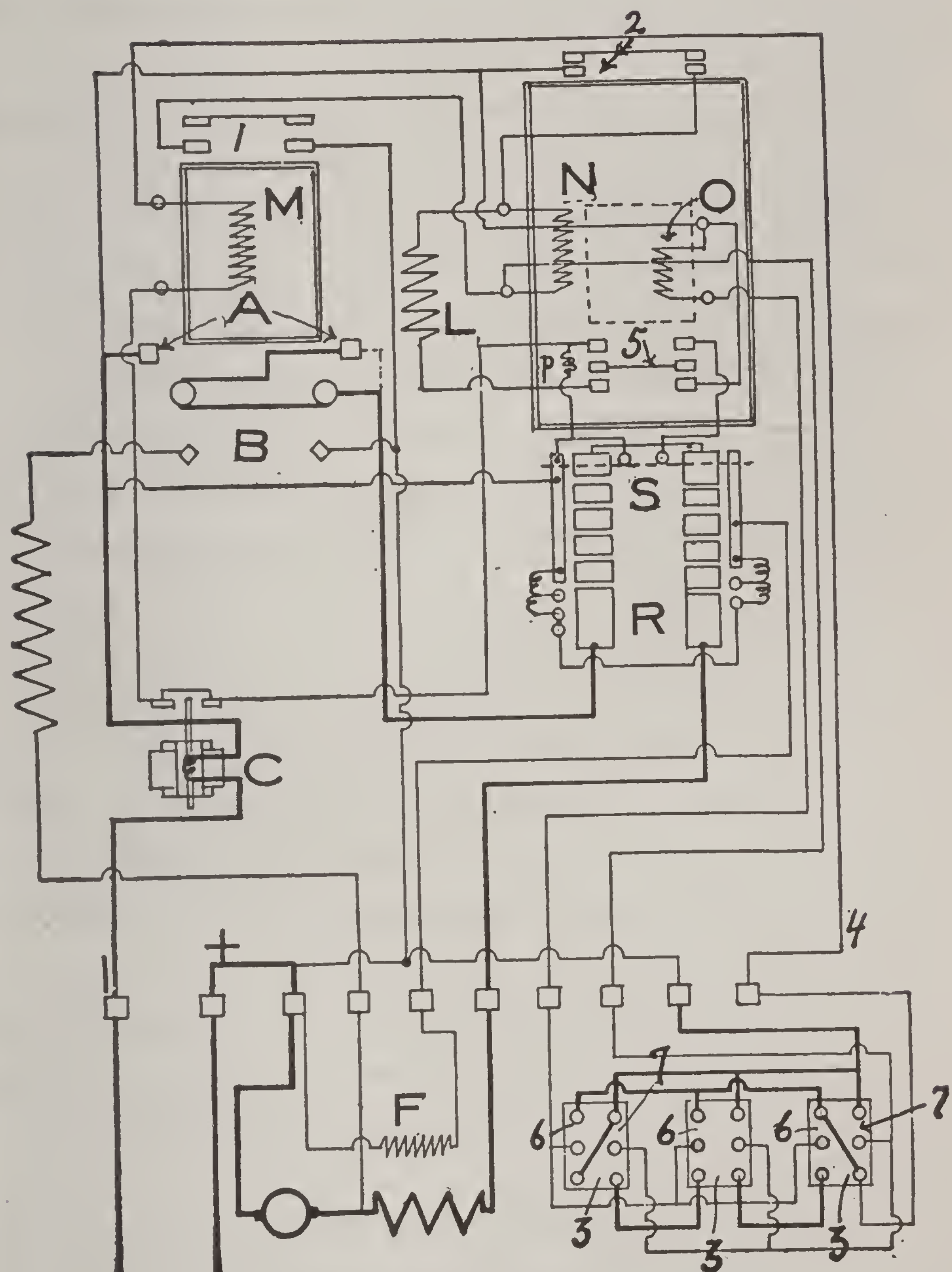


FIGURE 130a.

pulls up the contact bar of the rheostat R until it rests as indicated by dotted lines, thus cutting all of the resistance of R into the armature circuit.

When at rest in any position the solenoid is held in place by a ratchet device (not shown) and also by current which passes through N and the auxiliary resistance L at the left. The ratchet and also the circuit through N are controlled by another magnet O. This magnet when energized withdraws the ratchet and allows the bar to slip down and also opens the circuit through N. at 5. When the circuit of O is closed the solenoid N begins to move downward cutting out resistance until the circuit of O is opened when it comes to rest wherever it happens to be. Thus more or less of the resistance R may be left in the armature circuit.

The field circuit F can readily be traced and it can be seen that as the solenoid moves down to its lowest notch resistances are cut into the field circuit which weaken the field and cause the motor to attain its highest speed.

B is the brake circuit and when M descends after being deenergized it closes the armature circuit at B, thus short circuiting the armature and quickly bringing the motor to rest.

C is a circuit breaker and the plunger shown opens the circuit through M when the armature current exceeds its allowable value.

The various buttons by which the motor is controlled are shown in the lower right hand corner. There may

be any number of these buttons and they may be located at different convenient places about the machinery. From any one of these buttons the motor may be started or stopped. The operation is as follows: The motor cannot be started unless the solenoid N has drawn up the contact bar of the rheostat to its highest point closing the safety circuit at S. This is accomplished as soon as the main switch (not shown) is closed. Current passes from the positive pole of the circuit to point 1 which is closed until M is energized, thence through N to point 2 which is closed until N has acted, and from there to the negative pole of the line.

The middle bar at 5 rests upon the lower contacts there shown except when O is energized. When O is active this bar is drawn up against the upper contacts. Before current can be gotten into the armature circuit all of the points 3 on the buttons must be closed. When this is done circuit is established through wire 4, magnet M, resistance P and the negative pole of the line. Owing to resistance P this current is not of sufficient strength to close the armature circuit at A. When now one of the buttons is closed at 6 current is established through O to the negative pole of the line. This releases the ratchet before mentioned and also draws up 5, establishes a shunt circuit around P through S and strengthens the current in M sufficiently to draw up the core and close the armature circuit at A. This starts the motor at its slowest speed and allows the

contact bar of R to descend, thus cutting resistance out of the armature circuit and speeding up the motor. When the button 6 is released 5 again closes the circuit through L and holds N wherever it may be, thus keeping the motor running at that speed.

If the speed of the motor is to be reduced pressing one of the buttons 7 will cause the contact bar of N to rise and cut in more resistance into the armature circuit. The motor can be stopped by opening any one of the buttons 3, but all of them must be closed before it can be started. This is a safety arrangement of great value.

Another diagram of Kohler system printing press controller is given in Figure 130b. In this case the motor is reversible but can be used in the reverse direction at the slowest speed only. There is also a lock mechanism shown at P which can be set so that the motor can be operated at a fixed speed only. In this case it is intended that the pressman shall have no control over the speed but have full control over starting and stopping of motor.

The field and armature circuits can easily be traced and will need no explanation. There is also the brake circuit as in the preceding Figure 130a.

With the reversing switch indicated in the lower right hand corner thrown to the right, circuit is at once established through wire 1 solenoid N points 2 and 3, and the negative pole of the line. When N acts the circuit at 2 is opened and current is now forced through

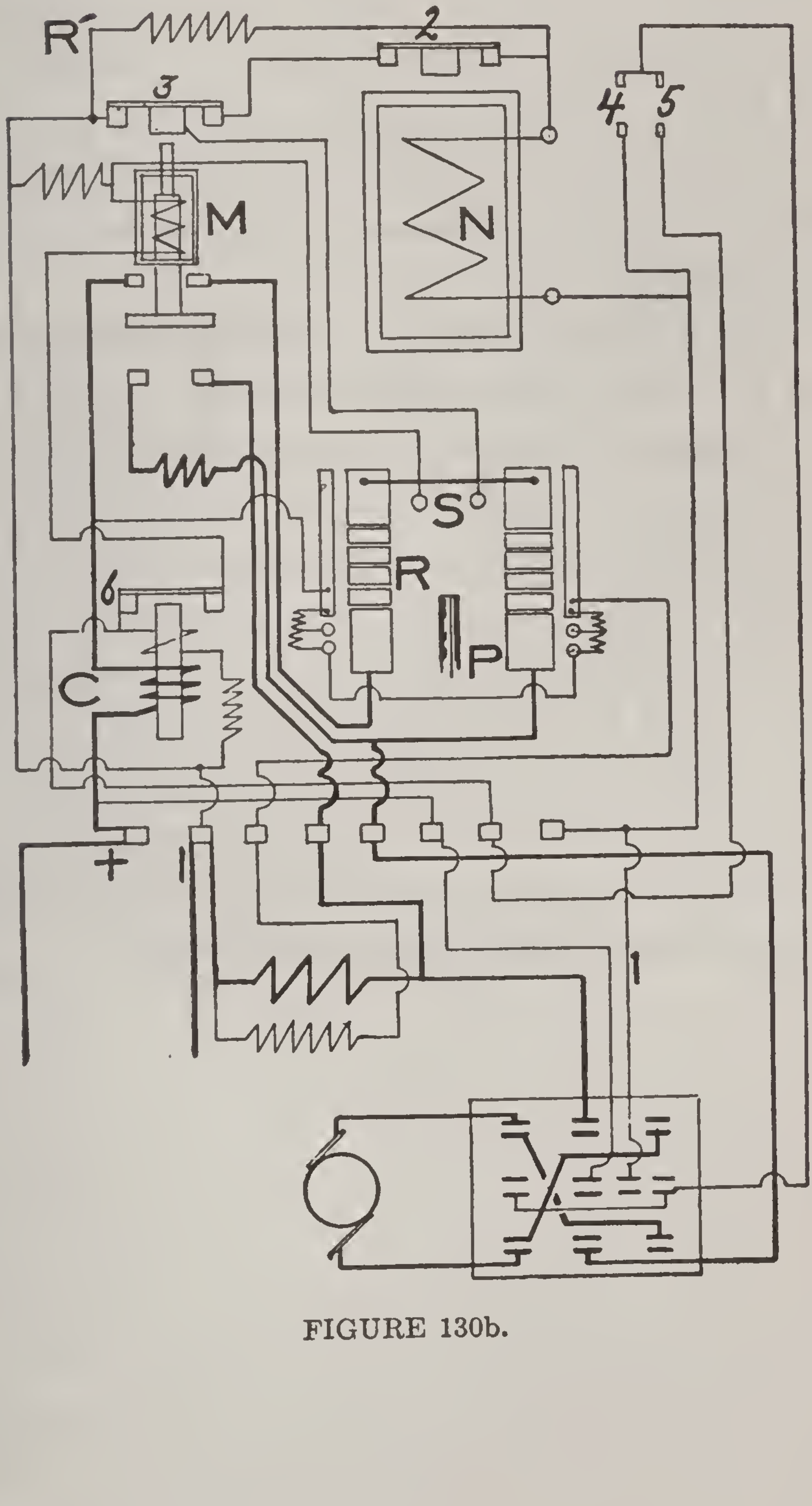


FIGURE 130b.

R′ which reduces it so as to be only sufficient to maintain N in its position. With the reversing switch thrown to the left there is current in N only while button 4 is closed and when this is opened the contact bar descends until it strikes the locked plug P the position of which determines the speed at which the motor shall run.

To close the armature circuit it is necessary to close button 5. This sends current through point 6, solenoid M, safety S, point 3 and negative pole of line. There is also a parallel circuit around the circuit breaker C which keeps the circuit open after an overload in the armature circuit has caused the breaker to act. For normal operation in the forward direction button 4 must be closed and remain closed until 5 is closed. When 5 is closed the armature circuit is closed and the motor starts at its slowest speed. To speed it up 4 must be opened; this allows N to descend and cut out resistance and speed up the motor.

CHAPTER XIII.

AUTOMOBILES.

ELECTRIC AND GASOLINE, CHARGING STATIONS, GAS ENGINES.

The following diagrams illustrate some of the methods of electric automobile wiring employed by the Woods Motor Vehicle Co., and much of the information herein given is taken from Mr. C. E. Wood's work, "The Electric Automobile."

Figure 131 shows one of the earlier methods and gives three speeds. The first speed is obtained by grouping the batteries four in parallel and ten in series. This connection is made when the controller connects all of the points along line *a* with the opposite points along line *b*. The circuit can readily be traced, the current passing from the + poles of the cells to bar 1, thence to Y, through both fields, F, to the reversing switch R; back to both armatures; through other side of reversing switch and to X, bar 2 and the — side of the batteries.

The second speed is obtained when the controller connects the points along line *a* with those along *c*. This places the battery in groups of two in parallel and twenty in series. The third step, by connecting

a and *d*, places all forty cells in series with the fields and armatures.

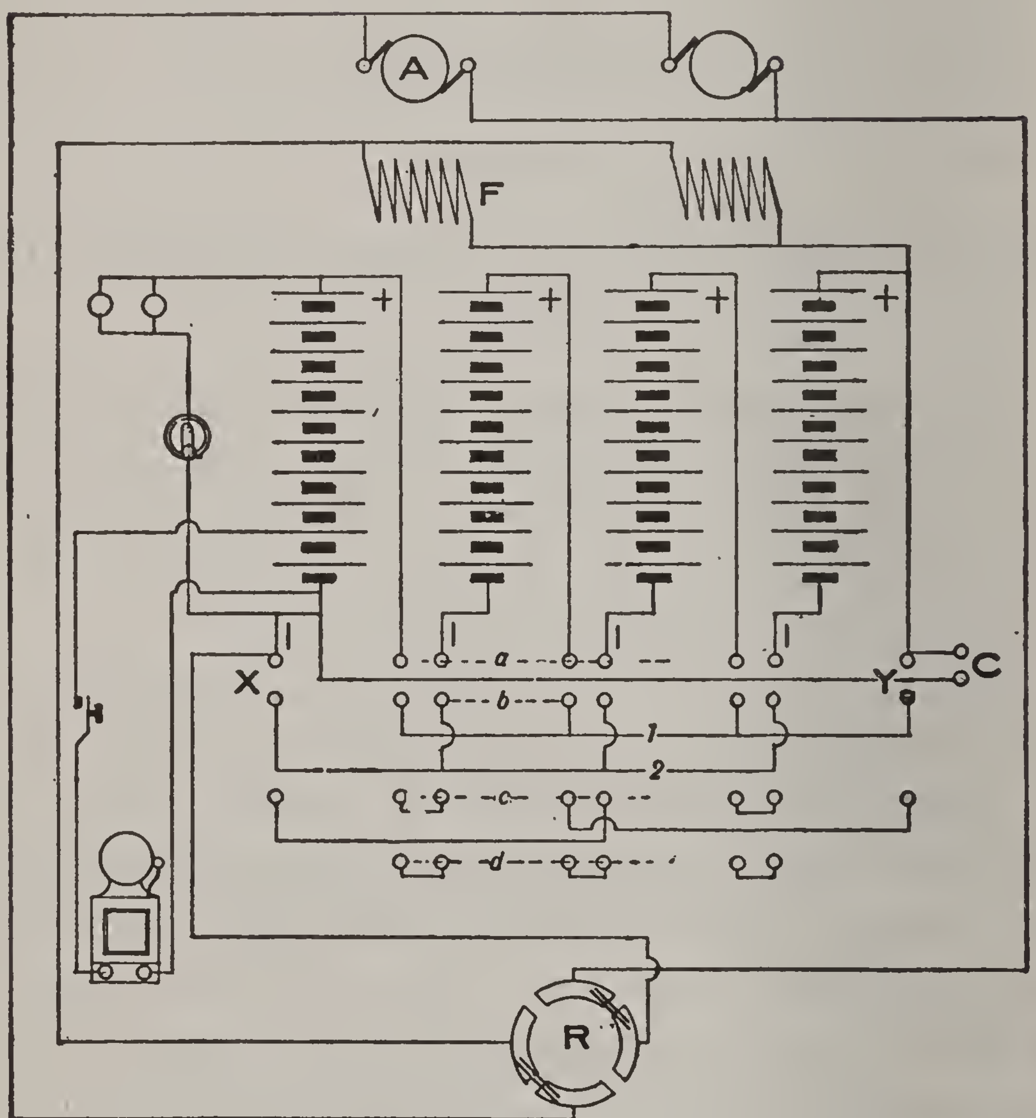


FIGURE 131.

Figure 132 shows an arrangement giving four speeds and in which not so many changes are made in battery connections, but more in those of the fields. As in the previous diagram both armatures always remain in parallel.

The first speed is obtained when the controller connects the points along *a* with those along *b*. The two halves of battery are now in parallel and work through both fields in series, the current passing from

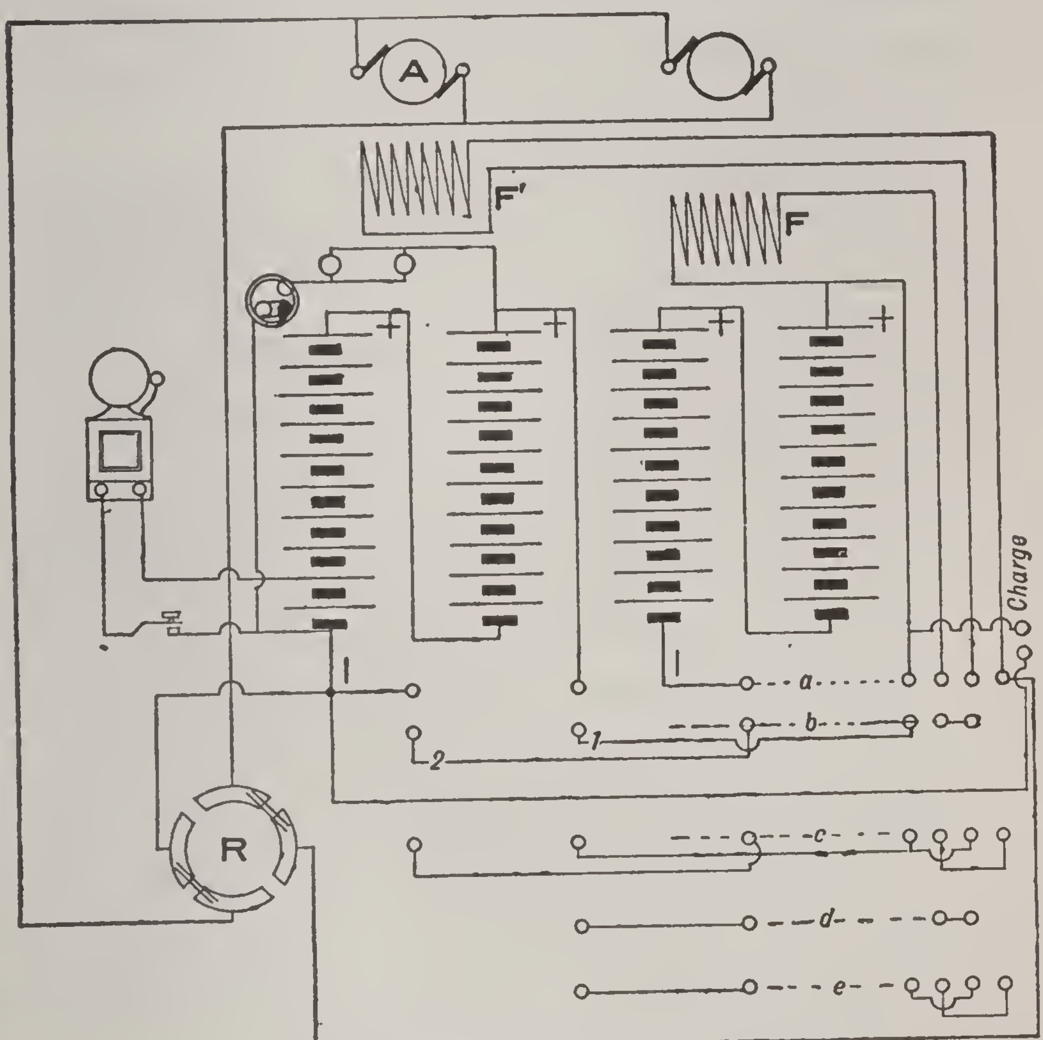


FIGURE 132.

the positive pole of battery to bar 1, thence to field F, back to controller and through F′, thence back to reversing switch R, through both armatures and again through reversing switch and back to negative pole of battery and bar 2.

The next step on the controller combines *a* and *c* and leaves batteries still in parallel and at the same time throws the fields in parallel thus weakening the fields and speeding up the motor.

The third step, combining *a* and *d*, throws the batteries all in series and the fields also, increasing speed through increased E. M. F.

In the fourth speed, connecting *a* and *e*, the batteries remain in series and the fields are again placed in parallel. The charging plug is shown at the right and to charge, the batteries are thrown in series. Connections for electric gong and lamps are also shown.

It will be noticed that with these motors fuses or circuit breakers are not used. It would indeed be quite dangerous to have a fuse blow out when climbing a steep hill. The whole wiring is therefore so designed that it can safely carry for a short time all that the battery can deliver. These diagrams show no resistances used as with other motors; the reduction of E. M. F. at starting by placing cells in parallel is far more economical and satisfactory. Vehicles have, however, been built which combine resistance control with the methods just described.

Figure 133 shows the arrangement of an automobile charging station. By means of the rheostat R the current is regulated to the needs of the battery. The charging plug P is usually so made that it can be inserted only one way so that the polarities of the charging dynamo and the batteries will always be cor-

rect. The voltmeter may be used to test the condition of the battery and also to indicate polarity of dynamo or battery if these are not known. The double-throw switch shown is needed only in case it is desired to test or "form" batteries. It provides an easy connection for discharging batteries.

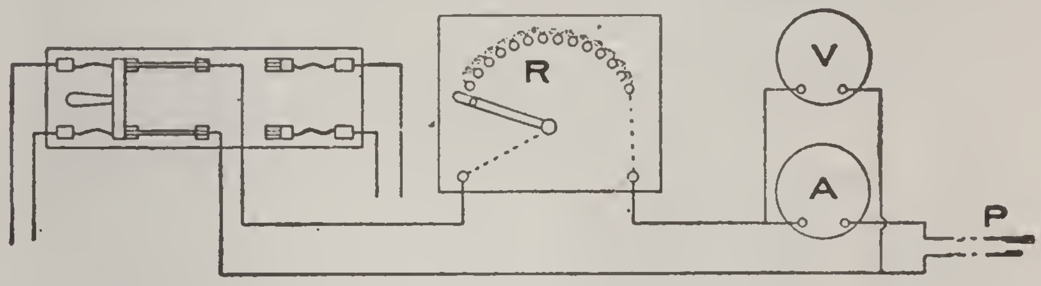


FIGURE 133.

In Figure 134 is shown the general principle of ignition used in gasoline automobiles. A jump spark is almost invariably used and this is produced by means of an induction coil capable of giving a very

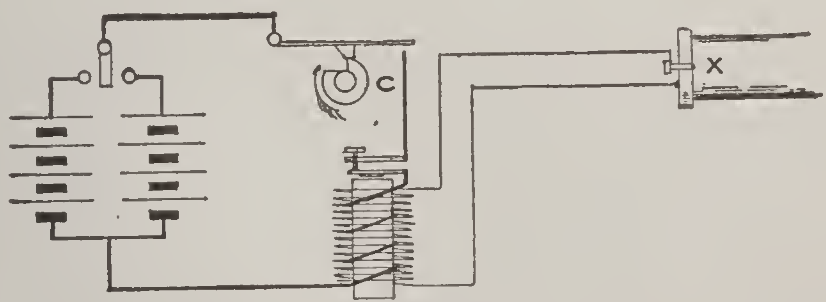


FIGURE 134.

high voltage. The figure shows an induction coil equipped with a vibrator, but this is not always used and many equipments dispense with it entirely. The cam C is connected with the gearing and adjusted so that it makes and breaks the circuit at just the proper

time for ignition. Whenever the current at C is broken a spark occurs at X. At this point a "spark plug" equipped with proper terminals across which the spark is to jump is fitted into the end of the cylinder.

Figure 135 shows a four-cylinder engine equipped with four sets of batteries and independent coils.

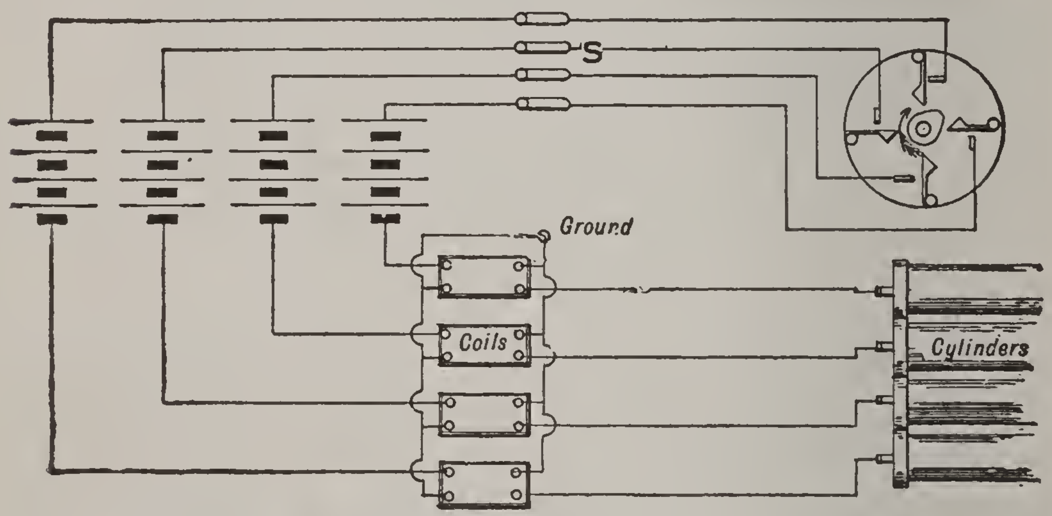


FIGURE 135.

An arrangement using either battery or generator is shown in Figure 136. Generators used in this connection are usually fitted out with some form of governor which keeps them running at a sufficiently uniform speed to allow of practical operation whether the car be running fast or slow. This figure also shows wiring arranged for a "double spark gap." A spark plug is very apt to "foul"; that is, to become covered with soot from the combustion of gas in the cylinder. When it is thus "fouled" the current leaks through the carbon from one terminal to the other and, of

course, there is no spark. The proper remedy is to either provide a new plug or clean the old one. It is, however, claimed by some automobile users that if another spark gap be introduced in series with the one which is "fouled" that both will then spark. Whether

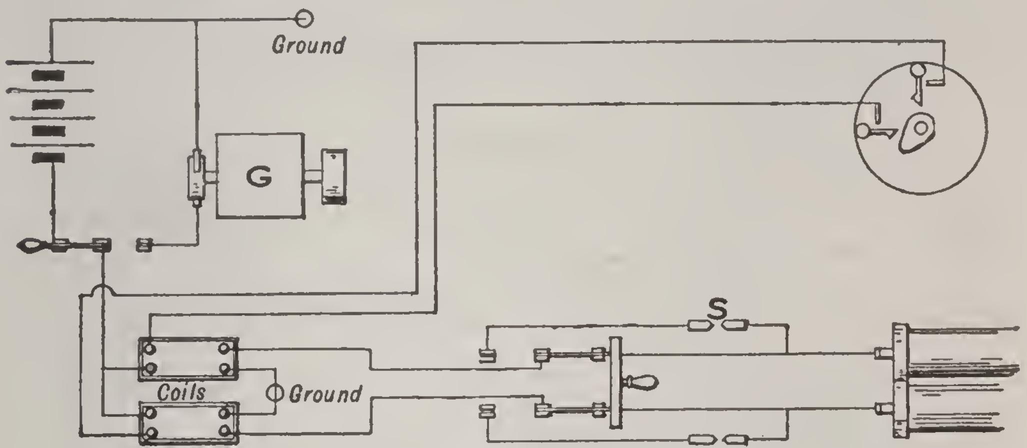


FIGURE 136.

this be true or not it can at best be only a temporary relief, for in time the plug in the cylinder will become so completely covered that it cannot possibly spark. The throw-over switch in Figure 136 admits using a single or double spark gap.

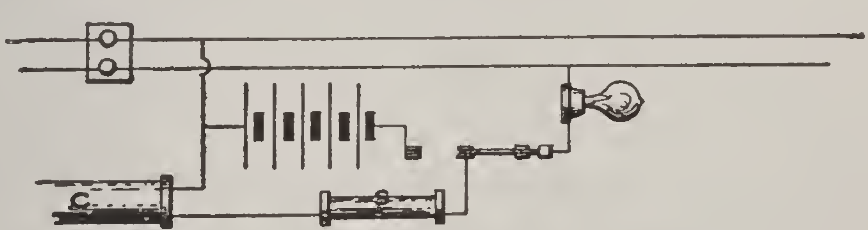


FIGURE 137.

In Figure 137 are shown the connections of a gas engine igniter where the gas engine is used to drive a dynamo supplying electric lights. The current is taken from an electric light circuit while the dynamo is running, a 50 c. p. lamp being placed in series with

the spark coil. While the engine is starting the battery is used to supply current for igniting the gas. The single-pole throw-over switch is arranged to make connections either way. This arrangement has the disadvantage that it usually "grounds" the electric light system and is therefore not approved by most insurance companies and inspection bureaus.

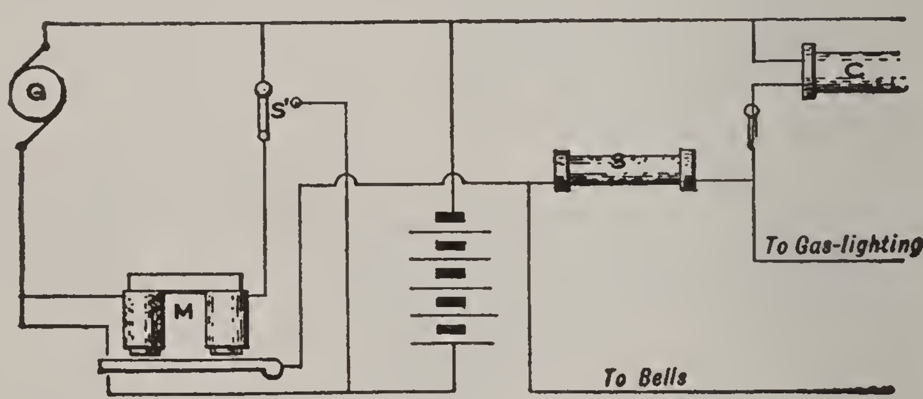


FIGURE 138.

Figure 138 shows another arrangement of gas engine ignition. The small generator G is coupled to the gas engine and driven by it. While the engine is at rest the armature of the magnet M closes the battery circuit on the spark coil and cylinder C of the engine. As the engine gains speed the generator G sends current through the magnet M and raises the armature, thus disconnecting the battery and closing its own circuit on the spark coil. If a storage battery is used it may be charged from time to time by throwing the switch S′ over. The switch near C may be opened to prevent accidental short circuits while the engine is at rest.

Figure 138a shows a typical wiring diagram of an automobile ignition circuit. The electrical system consists of a magneto geared to the engine drive shaft. There are two windings on the armature, a primary or low-voltage winding and a secondary or high-voltage winding. A circuit-breaking device, which is operated mechanically at each revolution of the armature, is attached to the armature shaft. A condenser, also on the armature, is connected directly across the circuit-breaker terminals. When the automobile is started the starting switch SS is closed and the circuit is completed through the dry batteries, intensifying coil and primary winding of the armature. When operated at the low speed of starting, the current generated by the magneto is not sufficient to produce a suitable spark and the generator current is therefore intensified by the dry batteries. The circuits in start-

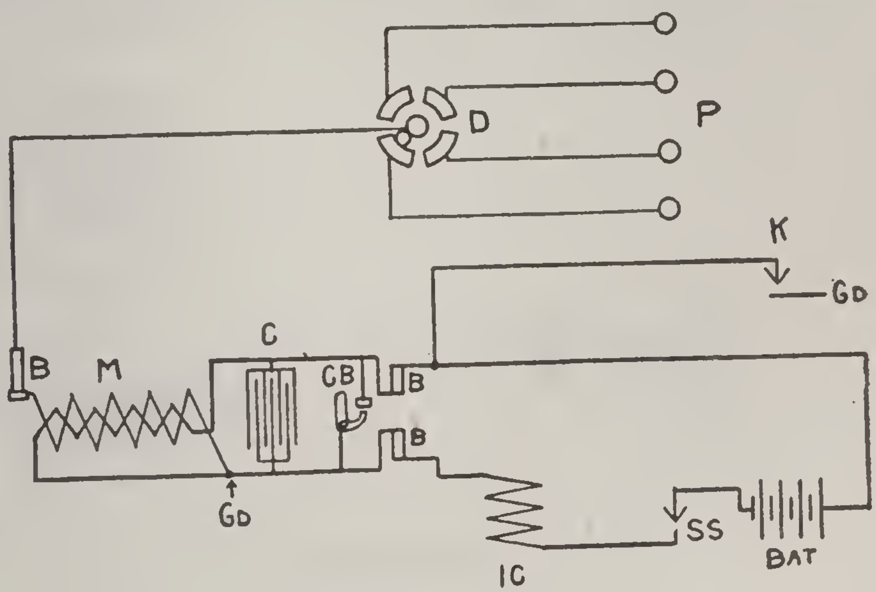


FIGURE 138a.

ing are as follows: Through the primary winding of the armature and through the circuit breaker which is closed. Paralleled with this is the battery circuit, through the intensifying coil IC, and then by means of the brushes BB through the circuit breaker CB. At the proper time for ignition the circuit breaker opens and the combined currents of the magneto and dry batteries induce a current in the secondary winding

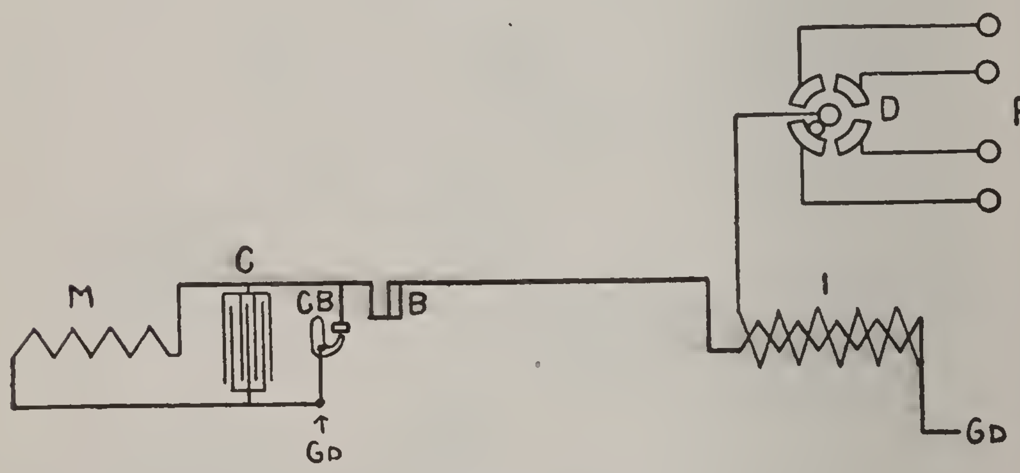


FIGURE 138b.

of the magneto, this winding acting as the secondary of a transformer. The induced, high-voltage current passes out through the brush B and by means of the distributor D to the proper cylinder. The secondary winding also generates a current which is added to that induced by the current in the primary winding. It is necessary to connect the battery so that the current flows in a certain definite direction through the circuit breaker, otherwise it will tend to neutralize the effect of the current generated by the magneto. The switch shown at K is operated by the insertion and

extraction of a key. When the key is withdrawn the switch is closed to ground and the circuit breaker is therefore shunted directly across and made inoperative. The insertion of the key opens this switch and permits the circuit breaker to perform its proper function.

Figure 138b shows the wiring diagram of an ignition system using, in place of the secondary winding on the armature of the magneto, an induction coil. The electrical action is similar to that described in Figure 138a except that the breaking of the magneto circuit induces a high-voltage current in the secondary of the induction coil. The condenser shown in both of these diagrams is provided to reduce the destructiveness of the arc which occurs when the circuit is opened at the circuit breaker. There are many variations of the circuits shown, but the principle is the same in most of them.

CHAPTER XIV.

DIRECT CURRENT GENERATORS, COMPENSATORS, ALTERNATORS.

A diagram of the circuits in the Western Electric Co.'s series arc dynamo is shown in Figure 139. Constant-current, series dynamos, like the constant-current, series motors, are not self-regulating, so that some mechanical means must be employed to keep the

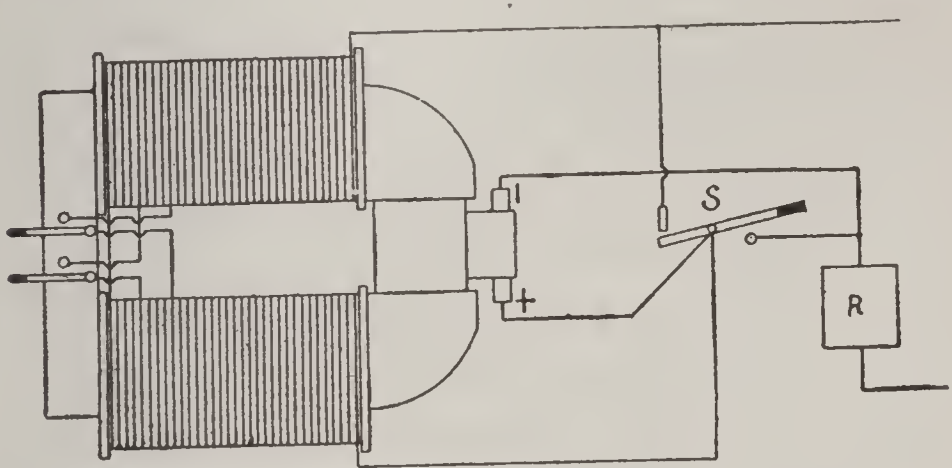


FIGURE 139.

current constant. This is accomplished by shifting the location of the brushes, or varying the number of exciting turns on the fields, or in some cases by both these methods combined. In the machine shown the voltage is regulated by shifting the brushes. In the diagram, current flows from the lower or positive brush to the center connection of switch S, and then around the fields and out to the positive side of the

line, returning through the regulator R to the upper brush. The switch S is used in starting and shutting down; in the position shown switch is set for running.

When it is desired to shut down, the switch S is closed. This first short-circuits the fields and then the armature. The switches shown at the left are used to cut down the current by short-circuiting part of the field windings. They are used where it is desired to operate either the 1200 c. p. arc lamp taking 6.8 amperes, or the enclosed arc lamp taking 6 amperes. With the switches in the position shown the machine will generate 9.6 amperes, the current generally used on the 2000 c. p. arcs. To reverse the direction of current the armature leads are reversed. In connecting two arc machines in series the + of one machine is connected to the — of the other. The positive side of the machine must always be connected to the positive side of the line.

Figure 140 shows the connections on a shunt-wound dynamo. The winding varies from that of the series dynamo in having the field magnets, which are wound with a great length of fine wire, connected in shunt across the dynamo brushes. The current in this field is then in shunt with the main circuit, and is generally about 2 or 3 per cent. of the whole current generated by the machine. Shunt-wound dynamos are used where a current of constant potential is desired, such as the lighting of incandescent lamps in parallel, furnishing power for motors and in stor-

age battery charging and electro-plating. Although the voltage of a shunt dynamo is practically constant, still, as the load is increased, the voltage will gradually fall, and this must be regulated by means of the rheostat R which is connected in series with the field. If resistance is cut out of the rheostat the current in the fields is increased, and the voltage of the machine rises, and *vice versa*. This dynamo is always protected from overload by a fuse or circuit-breaker placed in the main circuit.

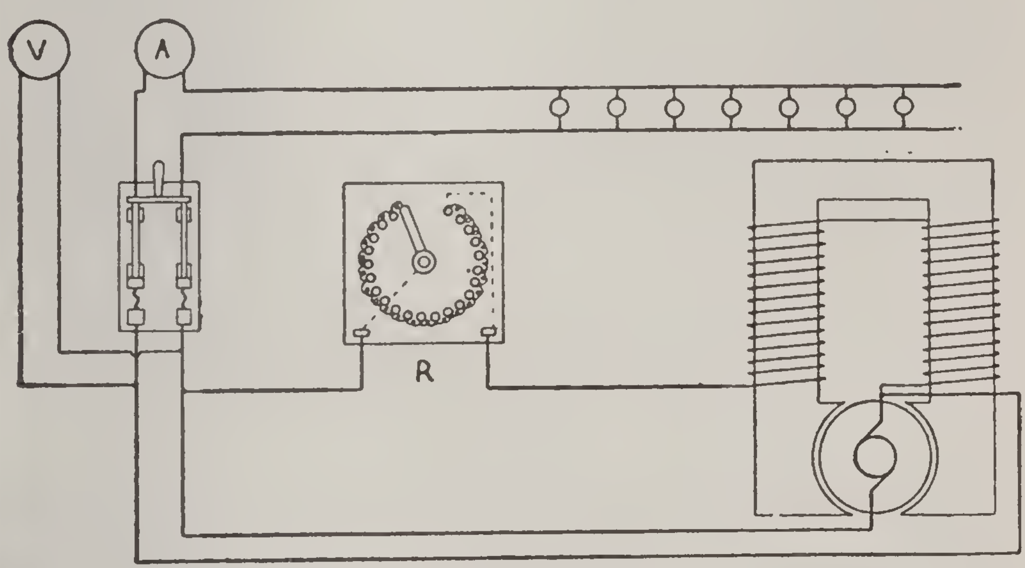


FIGURE 140.

To start the dynamo it is first brought up to speed and the voltage regulated by means of the rheostat R and the voltmeter V, and the main switch is then thrown in. The connection for the field is taken off the dynamo leads so that the opening of the main switch will not open the field circuit, and for this reason the field will begin to build up as soon as the

machine is started. Pilot lamps are sometimes used in place of voltmeter V, the voltage being determined by the brightness of the lamp. This is a very unsatisfactory method and is very little used at the present time. If either the armature or field connections are reversed current will flow in the opposite direction.

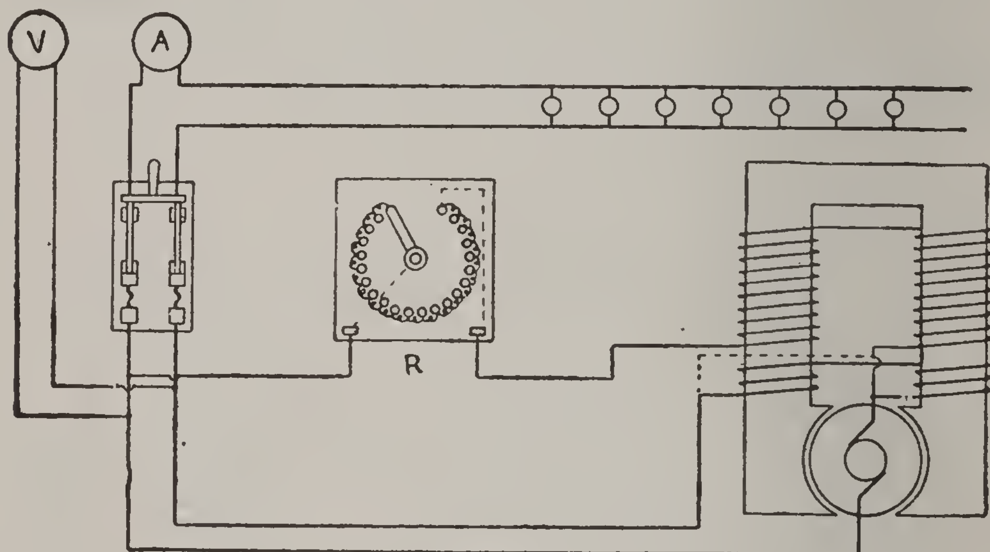


FIGURE 141.

Figure 141 shows the connections of a compound-wound dynamo. This machine, like the shunt-wound machine, is used where a current of constant potential is desired, but it has the advantage over the shunt machine in that it maintains the voltage more constant over a greater variation in load. The winding varies from that of the shunt dynamo in having, in addition to the shunt field, an auxiliary field which is in series with the armature. It is in reality the winding of both the shunt and series machine on one

machine. As the current supplied by the dynamo increases, the current in the series field winding increases, thus increasing the field magnetism and the voltage. In this way the voltage is kept practically constant.

When a dynamo of this kind is used to supply a large load located at some distance from the generator, it is sometimes desirable to have the voltage at the dynamo terminals increase as the load increases, to overcome the increased drop in the line due to the losses from increased current. To accomplish this a method known as over-compounding is used, the series windings being so calculated that, as the current increases, the voltage will rise accordingly.

In some cases the shunt field is connected between one brush and the end of the series winding, as shown in the dotted lines. This is known as the long shunt, the method of connecting directly across the brushes being known as the short shunt. A rheostat R is connected in the shunt field and serves the same purpose as in the shunt machine.

Figure 142 shows the connections when two shunt-wound machines are to be run in parallel. The winding of these machines is the same as shown in Figure 140. The positive lead of each machine is connected to the same bus bar. In starting, if it is desired to use but one machine, the method described in Figure 140 is followed. When one of the machines is running and the other is to be thrown in, the idle machine

is brought up to speed with the main switch open and the voltage regulated by means of the rheostat and voltmeter until the voltages of the two machines correspond. The main switch is then thrown in and the load on the two machines, which is ascertained by the ammeters, is equalized by means of the rheostats. If there is any great difference in voltage between the

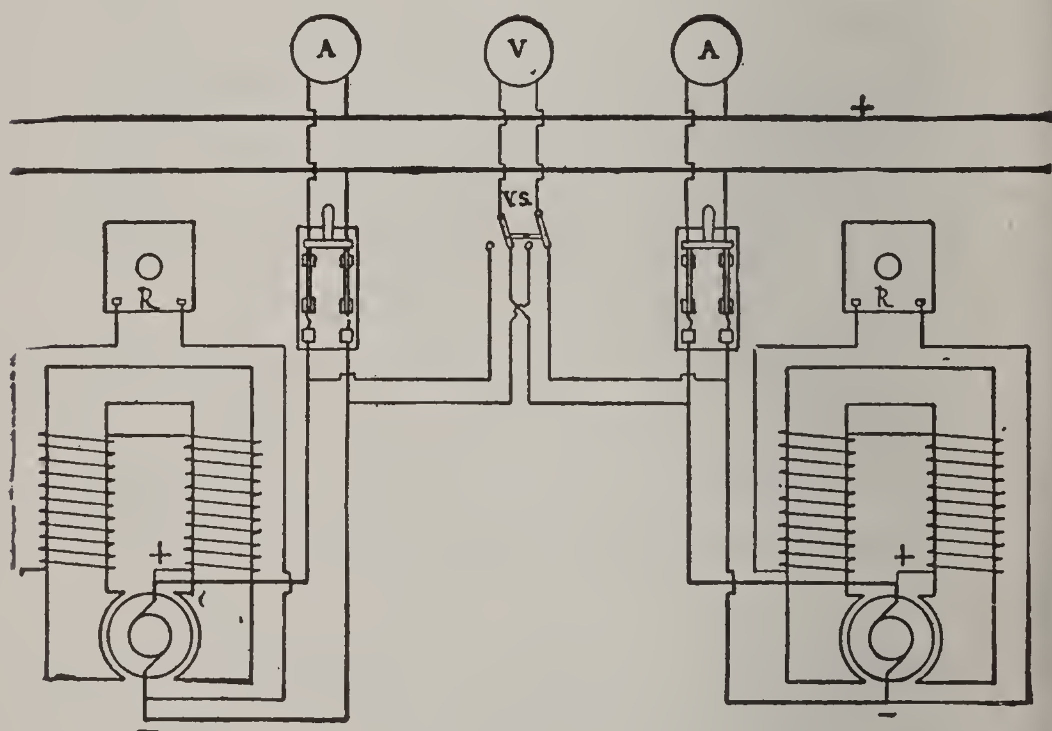


FIGURE 142.

machines, the higher one will run the other as a motor without changing the direction of rotation. The field current will remain unchanged and the armature current of the low dynamo will be reversed, which will cause it to run in the same direction as a motor as it ran as a dynamo.

When a plant feeding motors is shut down the switches on motors should first be opened, or very likely motor fuses will blow. As the voltage goes down the motors will draw more current to do the work. If a plant is shut down with the motor switches "on" it will generally be found impossible to start up a shunt dynamo, the low resistance in the mains not allowing enough current to flow around the shunt fields to energize them.

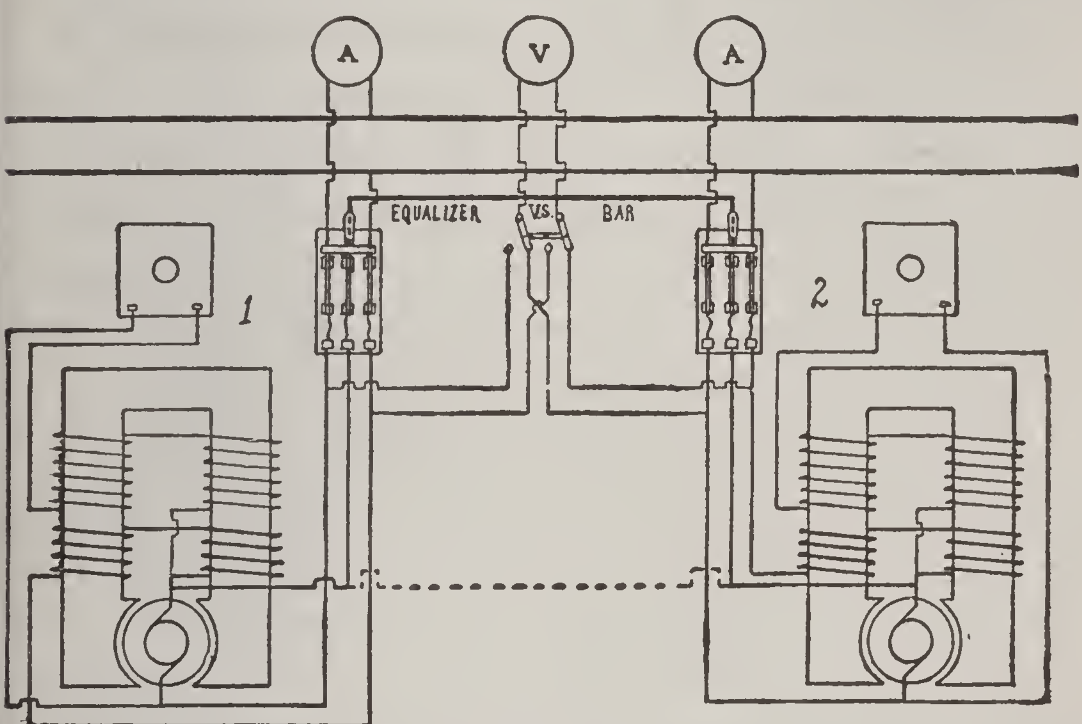


FIGURE 143.

Figure 143 shows connections for two compound-wound dynamos run in parallel, the winding of each machine being the same as in Figure 141. When two or more compound-wound dynamos are to be run together, the series fields of all the machines are con-

nected together in parallel by means of wire leads or bus bars, which connect together the brushes from which the series fields are taken. This is known as the equalizer, and is shown by the line running to the middle pole of the dynamo switch. By tracing out the series circuits it will be seen that the current from the upper brush of either dynamo has two paths to its bus bar. One of these leads through its own fields, and the other, by means of the equalizer bar, through the fields of the other dynamo. So long as both machines are generating equally there is no difference of potential between the brushes of Nos. 1 and 2. Should, from any cause, the voltage of one machine be lowered, current from the other machine would begin to flow through its fields and thereby raise the voltage, at the same time reducing its own until both are again equal.

The equalizer may never be called upon to carry much current, but to have the machines regulate closely it should be of very low resistance. It may also be run as shown by the dotted lines, but this will leave all the machines alive when any one is generating. The ammeters should be connected as shown. If they were on the other side they would come under the influence of the equalizing current and would indicate wrong, either too high or too low. The equalizer should be closed at the same time, or preferably a little before, the mains are closed. In some cases the middle, or equalizer, blade of the dynamo switch

is made longer than the outsides to accomplish this. The series fields are often regulated by a shunt of variable resistance. To insure the best results, compound-wound machines should be run at just the proper speed, otherwise the proportions between the shunt and series coils are disturbed.

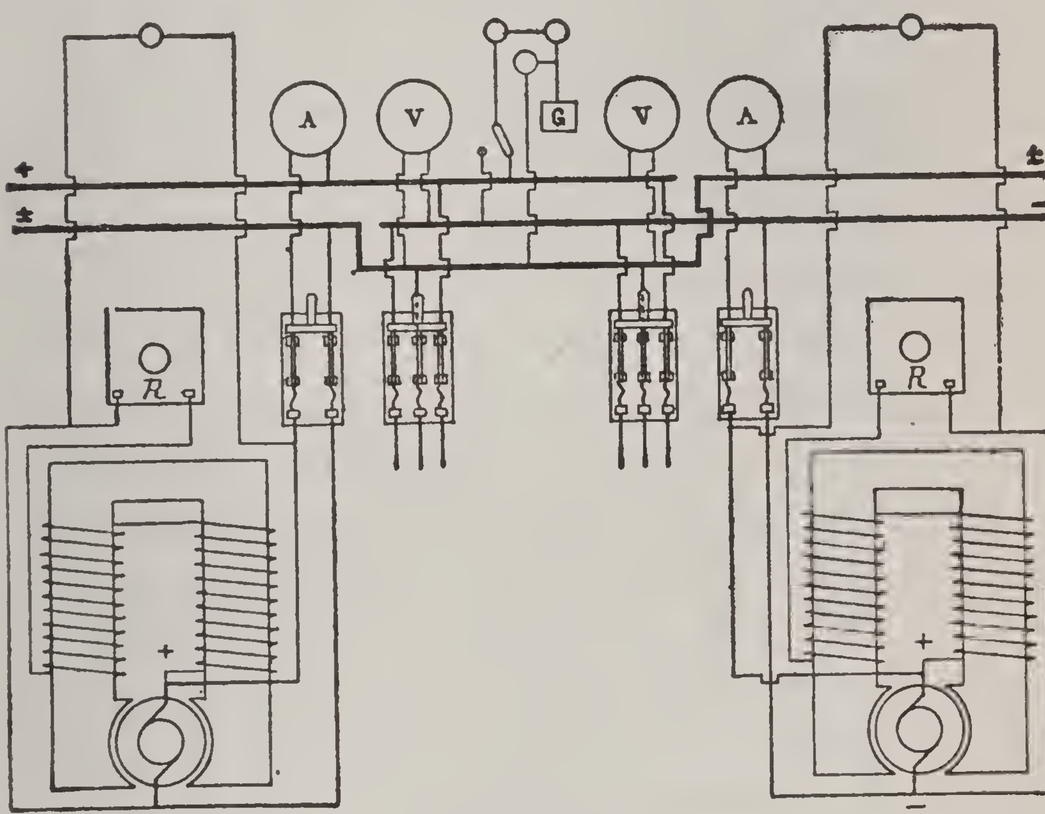


FIGURE 144.

Figure 144 shows connections where two shunt-wound machines are connected to operate on what is known as the three-wire system. The two dynamos are connected in series, three wires being carried from them; one from the outside pole of each machine and one from the junction of the two machines. The voltage between these outside wires is equal to the

combined voltage of the two machines, and the voltage between the outside and the central or neutral wire is equal to the voltage of the corresponding machine. If the load on both sides of the system is equal there will be no current flowing in the neutral wire, while if the loads are unequal the neutral wire will have to carry only the difference in currents between the two outsides.

The advantage derived from the use of the three-wire system lies in the fact that one wire (which would have to be used were the two machines operated on two separate circuits) can be done away with, and on account of the voltage being doubled the wires can be of much smaller capacity. For the same per cent of loss the amount of wire required to operate the three-wire system, when the neutral wire is of the same size as the outsides, is but three-eighths of that required with a two-wire system. This system is used to a great extent in the large cities for central station, direct current distribution, and it is also used on the secondary mains in alternating current work.

In the feeder lines of the direct current system the neutral wire is generally made one-third the size of the outsides, while in the secondary mains in both direct and alternating current work all three wires are made of the same size; for, if one of the outside fuses should blow, the neutral would have to carry the full current.

Figure 145 shows a diagram of the winding and connections of a Western Electric compound-wound compensator set. This apparatus is used in connection with 220 volt generators and by means of it a three-wire 110-220 volt system is obtained. This set consists of two motors, the armatures of which are mounted on the same shaft so that both run at the same speed. When the machines are started the switch P and the circuit-breaker are left open and the switch shown at the left closed. The machines are then started by means of the starting box. Tracing out the circuits it will be seen that the main current from the positive pole of the switch passes through the starting box, through the armature and series fields of machine B then through the armature and series fields of machine A and back to the negative side of the line. The circuit for the shunt fields is connected to the starting box, current flowing through the resistance box, R, and then through the shunt fields of machine A and machine B, these fields being connected in series, to the negative side of the line. It will be noticed by the direction of the arrows that the current in the series fields and the shunt fields are in opposition. This remains so in both motors only while the load on both sides of the neutral is even and under this condition the amount of current in the series fields is very small. If an additional load is thrown on one side, say ten lamps at X, part of the excess current flows along the neutral wire to the

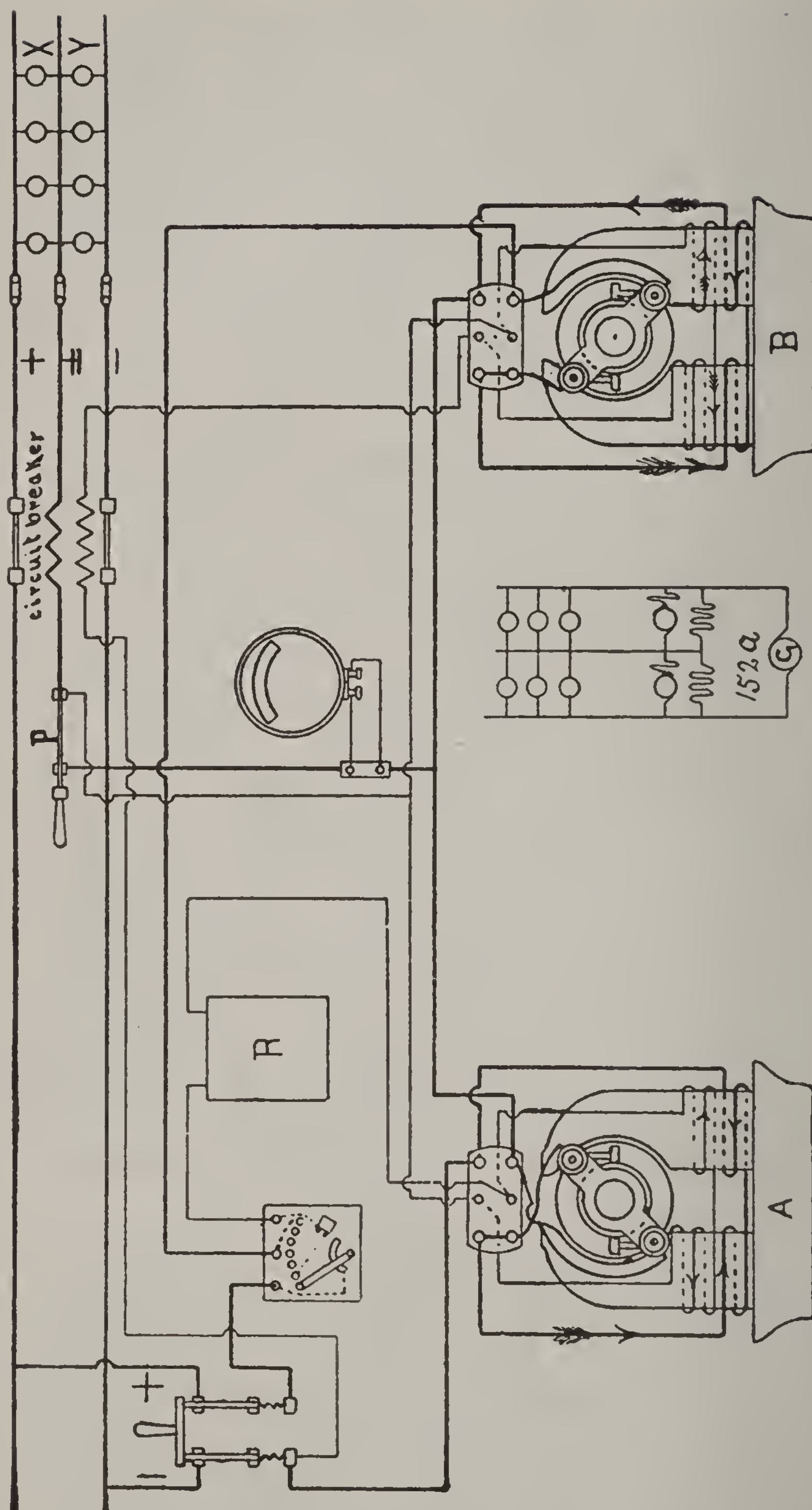


FIGURE 145.

armature and series fields of machine A. This current being in opposition to the current in the shunt fields weakens them and tends to speed up this motor. This speeding up increases the counter E. M. F. of machine B, the fields of which have not been weakened, and current flows out of the armature and through the series fields in a direction opposite to that shown by the arrows. The current in both field coils in this machine will now be in the same direction and the machine will act as a compound-wound generator. It cannot as a generator give out more power than it receives from A as a motor and will generate a little less than one-half of the excess current used at X. This is shown a little plainer by the diagrams in Figure 146. With no load, or with the load evenly distributed on both sides of the neutral, the conditions will be as shown in the upper diagram, both machines acting as motors. With excess of load between the positive and neutral approximately one-half of the excess current will pass along the neutral wire through the lower machine causing it to act as a motor while the balance of the excess current is supplied by the upper machine acting as a generator. The lower diagram shows the conditions with excess load between the neutral and the negative. In the operation of these machines, when they have attained full speed after starting, their voltages are equalized by means of the resistance box R, this box being placed in the strongest field. When automatic start-

ing boxes are used, as in this case, it is almost always necessary to place the resistance box in the opposite field to balance the resistance of the magnet on the starting box. For equalizing the voltages connections are made to the voltmeter as shown in Figure

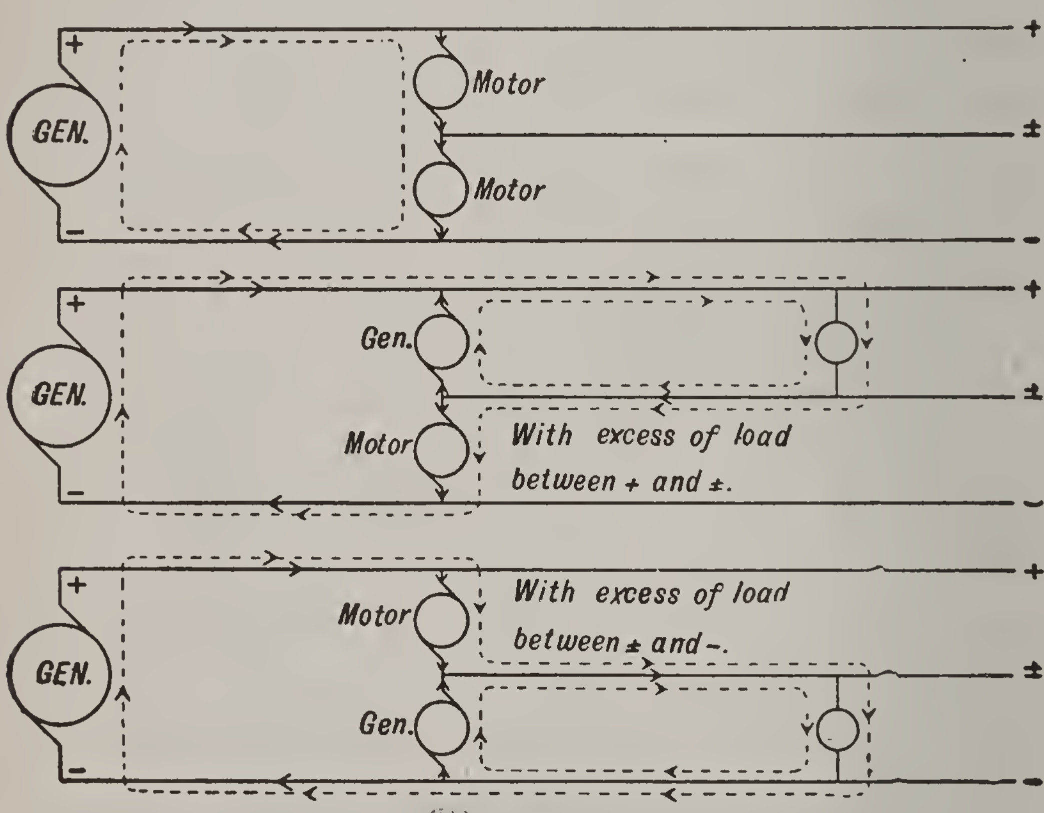


FIGURE 146.

143, so that reading for both machines can be taken. When the machines are at even voltage the circuit breakers are thrown in.

Figure 147 shows the switchboard and machine connections for two Compensator sets in parallel. The two panels at the left are for the 220 volt generators, the two at the right are for the feeders while

the two center panels are for the operation of the compensators. By following out the circuits for the

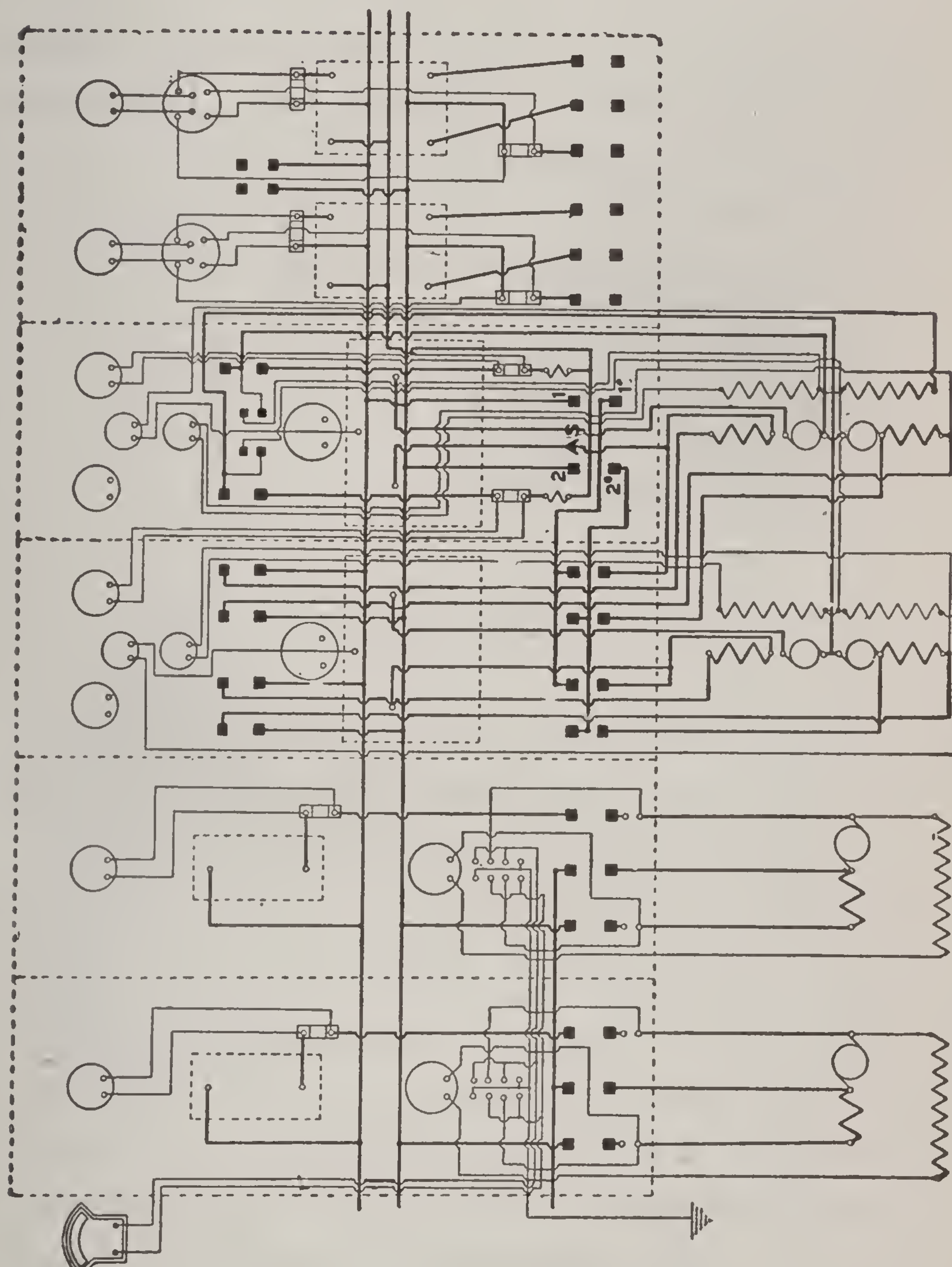


FIGURE 147

individual compensators it will be seen that, with few exceptions, they correspond to the circuits shown in

Figure 145. A resistance box is installed in each shunt field circuit while in Figure 145 there is only one resistance box.

The principle of the Westinghouse Three Wire Generator is illustrated in Figures 147a, 147b, and

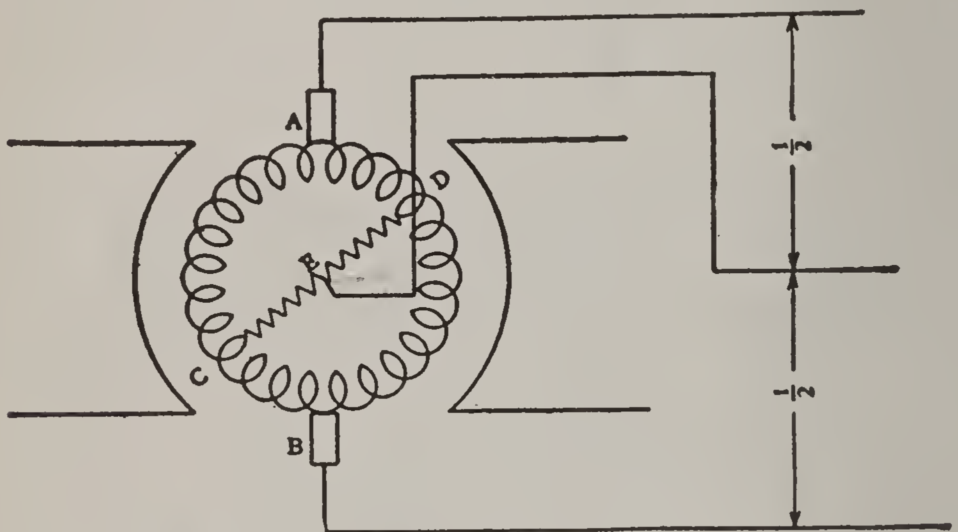


FIGURE 147a.

147c. Figure 147a shows the connections of the dynamo armature. The outer circle represents the ordinary armature winding connected by means of the commutator to the brushes A and B. The fine coils shown running through the center from C to D represent taps taken from diametrically opposite points of the direct current winding. If these taps are joined through resistances as indicated alternating currents will circulate in them and at E there will be a point at which just half of the voltage of the direct current system exists. The wire connected to this point can therefore be used to fulfill the same requirements as the neutral wire in the ordinary two generator three wire system.

The connections of a single machine are shown in Figure 147b. In actual practice the alternating current connections of the armature are connected to two auto transformers as shown. These auto transformers are known also as balancing coils.

Figure 147c shows the switchboard connections for two such generators operating in multiple. On

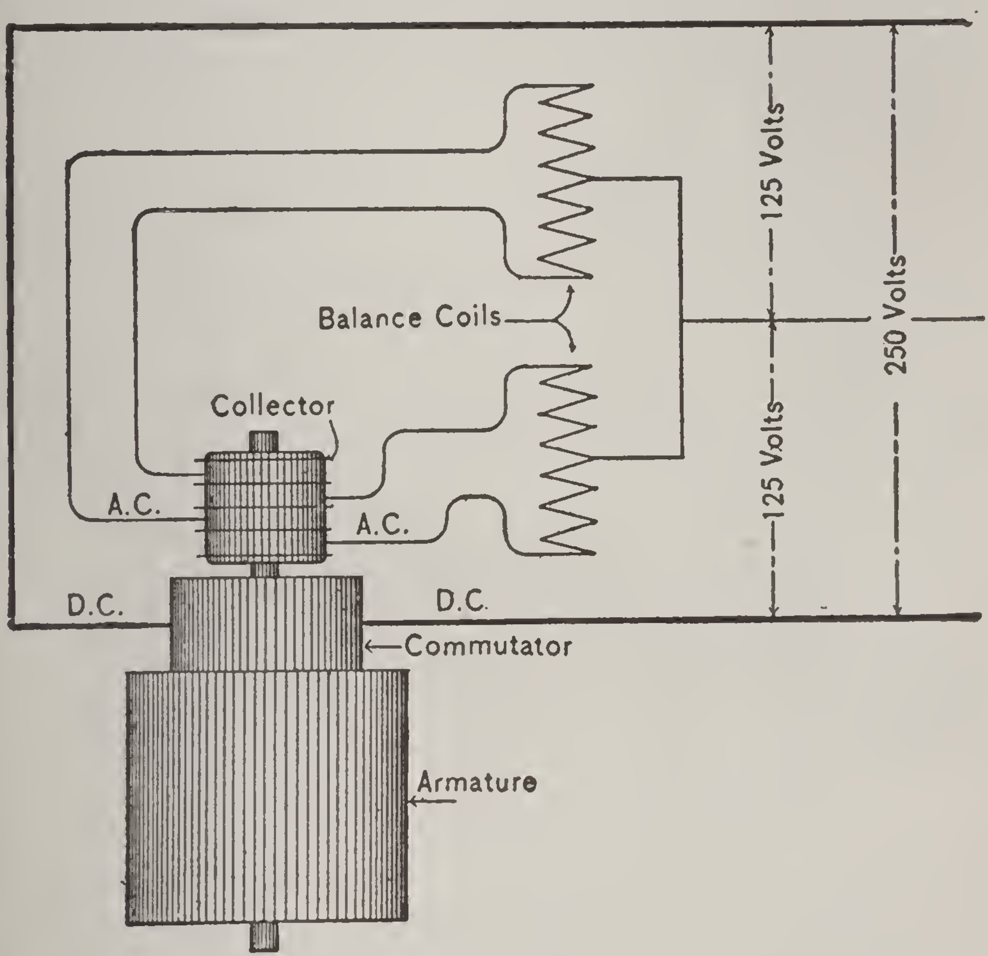


FIGURE 147b.

account of the fact that the load is often unbalanced an ammeter is provided in each leg leading from a machine to the switchboard. The series fields of each machine are also divided so that current from each leg may pass through half of each field. Since the

series fields are divided it is necessary to run an equalizer for each division and two are therefore shown.

The balancing coils should be mounted as near to the dynamos or switchboard as practicable. Any great resistance introduced into their circuit will affect the voltage existing between the neutral point and the outside wires. It should be noted that both the positive and negative equalizer connections as well as both the positive and negative leads are run to the cir-

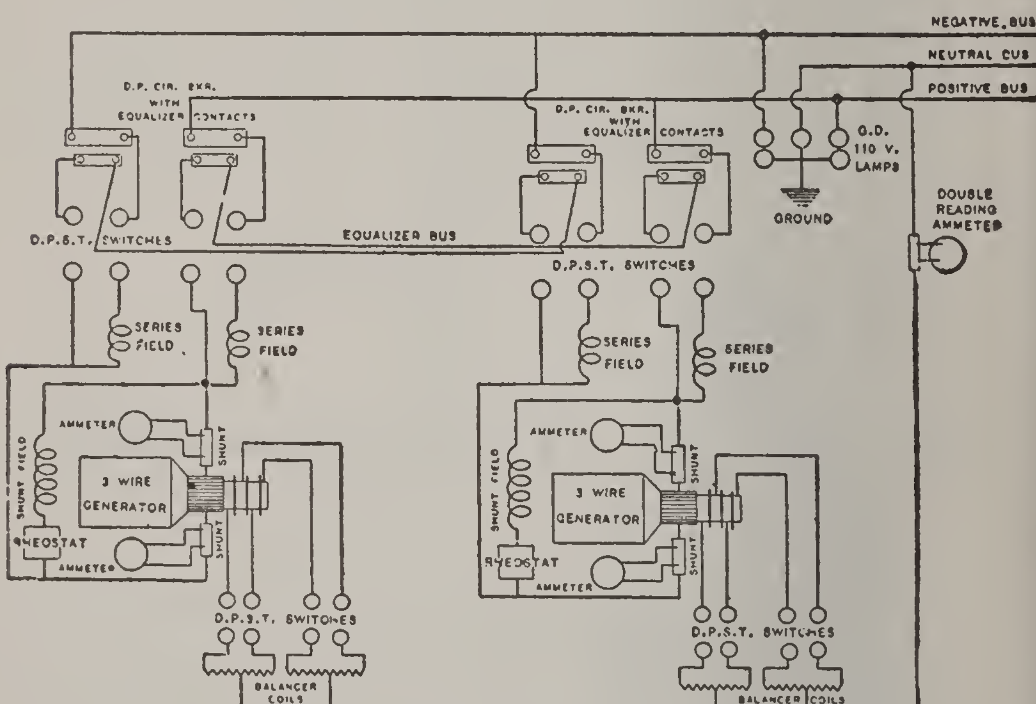


FIGURE 147c.

cuit breakers in addition to the main switches on the board. This is necessary in all cases. Otherwise, when two or more machines are running in parallel and the breaker comes out opening the circuit to one of them but not breaking its equalizer leads, its am-

meter is left connected to the equalizer bus bars and current is fed into it from the other machines through the equalizer bars either driving it as a motor or burning out the armature.

Once properly installed the balancing coils require no further attention and give no trouble. Provision should however be made so that their circuit cannot be opened accidentally while in operation.

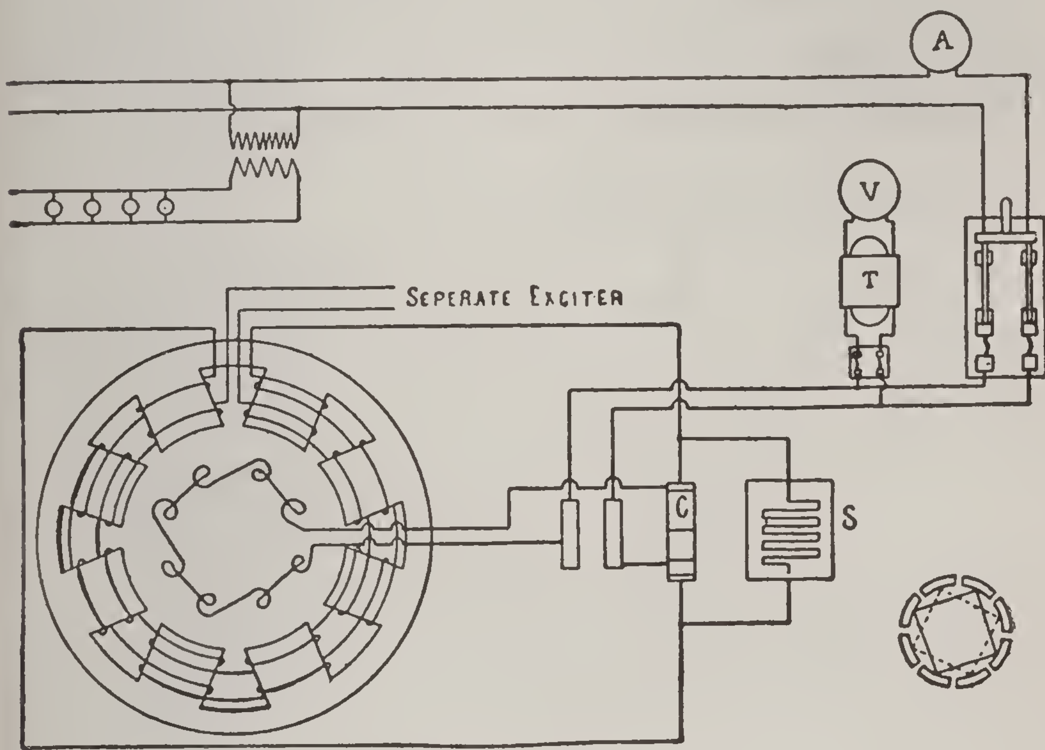


FIGURE 148.

Figure 148 shows the connections of a single-phase, alternating current generator. The field of this machine is excited by a direct current, part of which is taken from some outside source (generally a small dynamo belted to the shaft of the alternator) and part of which is taken from the windings of the alternator, the current being rectified by means of the

commutator C. This commutator has as many segments as there are poles to the dynamo, and the alternate segments are connected together as shown in the small diagram. S is a German silver resistance which is connected in shunt across this rectifying commutator. The main current coming from the armature is shunted, part going through the shunts, the remainder around the field winding.

It will be seen that this method of field excitation is very similar to that used on the compound-wound direct-current dynamo. In the diagram shown both

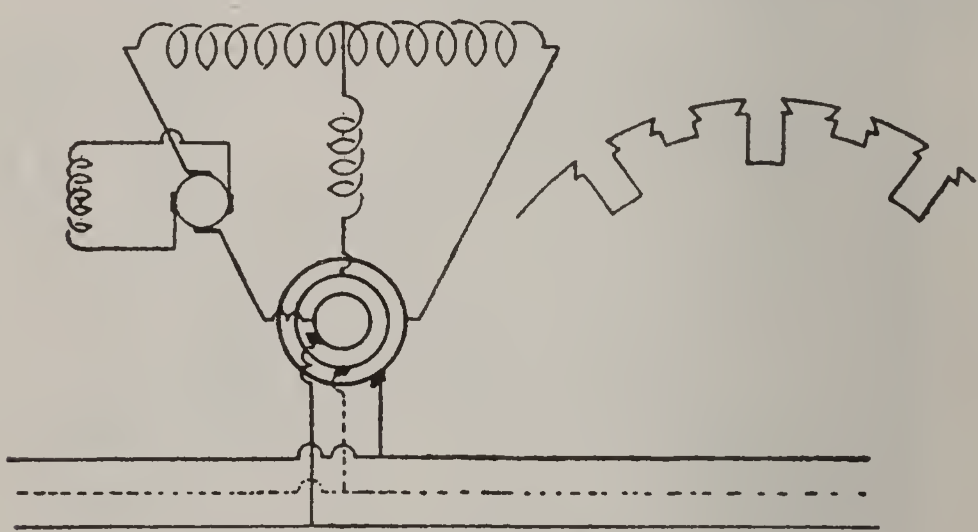


FIGURE 148a.

of the field windings encircle every pole, but in some machines the rectified current will traverse a few poles only, the current from separate exciter traversing the remainder. Current on these machines is usually generated at high voltage, and transformers are used at the point of supply to cut the voltage down to that required. The transformer T is used

in connection with voltmeter V to reduce the voltage on that instrument.

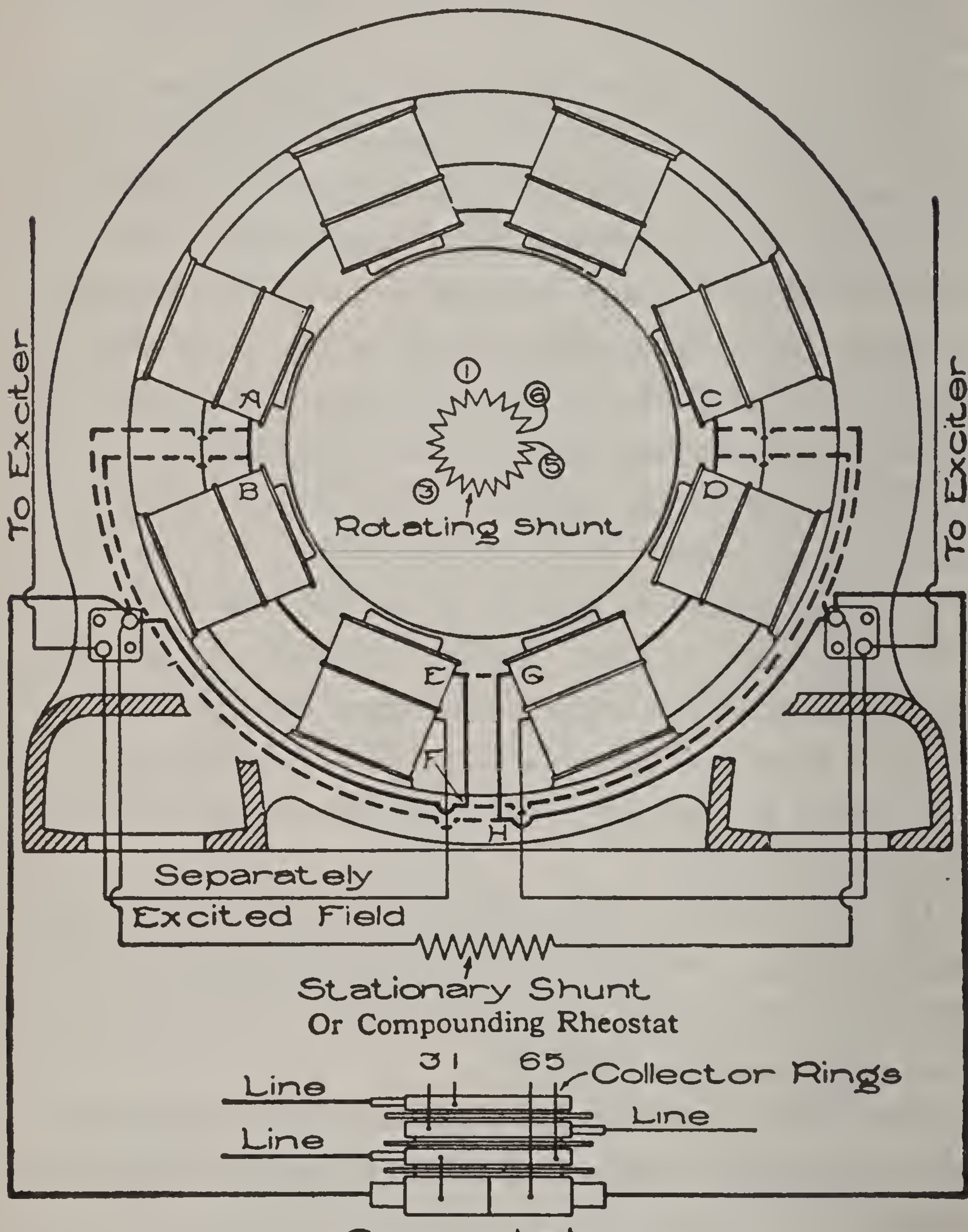
Figure 148a shows a theoretical diagram of a monocyclic generator of the General Electric Co. Such generators are sometimes used on systems where the lighting load is the main factor and only a few self starting motors are to be operated. It is essentially a single phase alternator with an extra winding of smaller capacity placed so as to produce a phase difference of 90 degrees between the currents in the main coil and those in the smaller. The smaller winding is known as a "teazer" coil, and the middle wire to which this coil attaches is spoken of as the "teazer" wire. The machine carries three collector rings. The arrangement of the wires placed upon the armature can be seen from the figure at the right. The main coils are placed in the deep slots and the teazer coils into the shallow ones.

In the General Electric generator, if the voltage between the two main wires is 2080 there will be difference of potential between either of the outsides and the teazer of 1160.

The field connections of a monocyclic generator are shown in Figure 148b, and the diagram is self explanatory.

The armature connections are given in Figure 148c, and the following instructions are quoted from the General Electric Co. "The armature of a standard monocyclic generator rotates in the counter-clockwise

CONNECTIONS OF MONOCYCLIC GENERATOR



CONNECTIONS FOR SERIES FIELD

For 2300 Volt Generators, connect as shown by solid lines. For 1150 Volt Generators, omit connections *A* to *B*, *C* to *D*, *E* to *F*, and *G* to *H*, and connect as shown by dotted lines.

FIGURE 148b.

direction as one faces the commutator. When the generator is loaded, the voltage between the teazer coil and the two terminals of the main coil may be different; therefore, it is necessary to have the commutator connected in corresponding ends of the main coil.

"If the machine has not been arranged for clockwise rotation the following change in the connections on the commutator-collector must be made if the machine is

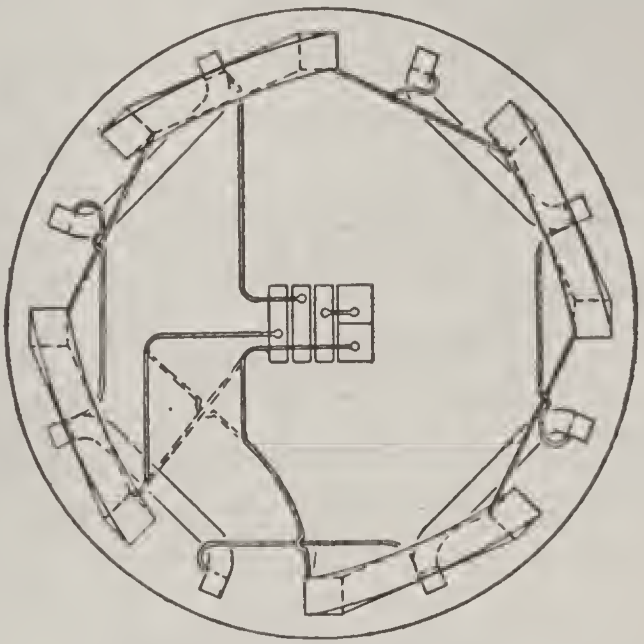
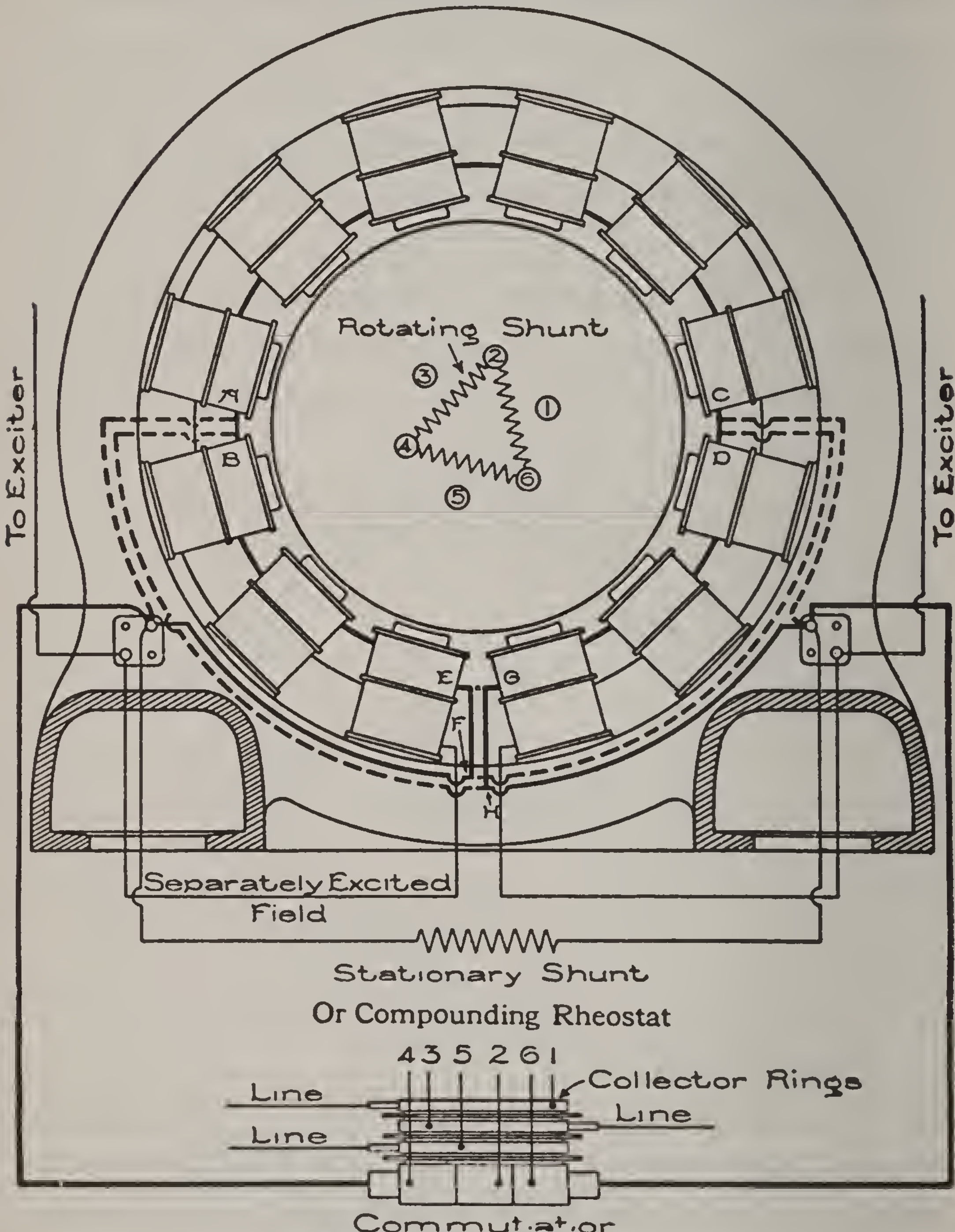


FIGURE 148c.

to be run in parallel with another. The diagram Figure 148b shows the connections of monocylic generators. In this diagram the studs on the commutator-collector marked 1 and 6 are the terminals of the main coil. These should be reversed. The numbers are stamped on the end of the stud and may be seen with the aid of a mirror. By referring to the diagram it is

CONNECTIONS OF THREE-PHASE GENERATOR



CONNECTIONS FOR SERIES FIELD

For 2300 Volt Generators, connect as shown by solid lines. For 1150 Volt Generators, omit connections *A* to *B*, *C* to *D*, *E* to *F*, and *G* to *H*, and connect as shown by dotted lines.

FIGURE 148d.

a simple matter to trace out the connections with the aid of a magneto, after the armature leads have been disconnected and the brushes raised."

Figure 148d shows the connections of a General Electric three phase generator. This machine, as well as all of the foregoing, is of the revolving armature type. Many of the larger machines are now built with stationary armatures and revolving fields. In such case the exciter feeds the moving element and the line currents are taken from the stationary windings.

Two three phase composite wound generators are shown connected together for parallel running in Figure 148e.

Composite wound alternators if used with inductive loads require considerable attention at the rectifier. A change in the angle of lag of the current behind the E. M. F. must be followed by a change in the adjustment of the rectifier or there will be much sparking. For this reason such machines are used mostly on lighting circuits only.

Figure 148f gives the switchboard connections of two two phase machines arranged for parallel running. Each machine is equipped with a throwover switch by which either phase may be connected to voltmeter. Each phase is also equipped with an ammeter.

E E are the rheostats by which the field strength of either machine can be adjusted. The synchronizing bus S is equipped with a throwover switch so that the synchronizing may be either dark or bright.

Whichever method is preferred should be settled upon and the switch locked so that it may not be accidentally changed. Synchronizing lamps of double the voltage capacity of the system must be provided as the two

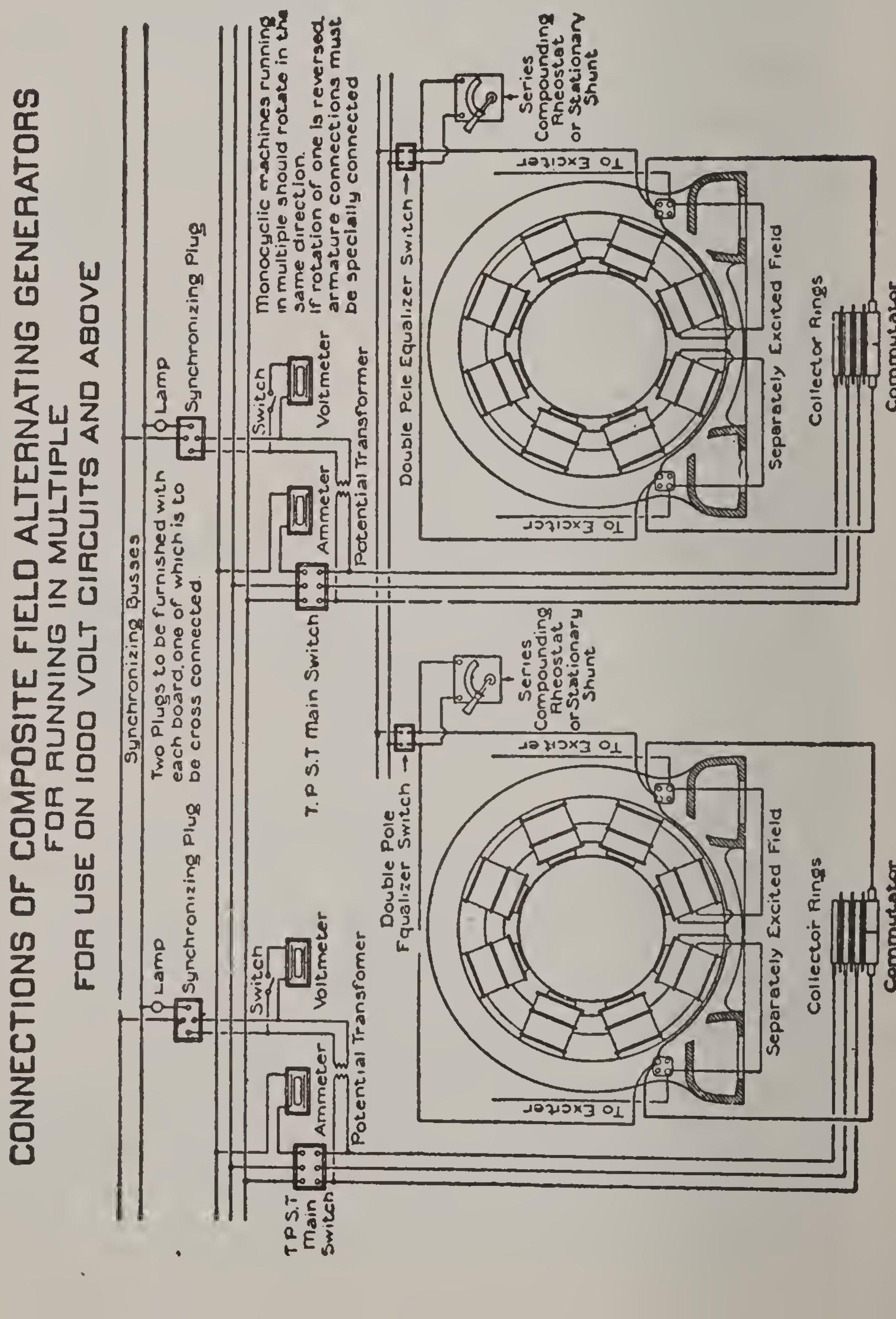


FIGURE 148e.

machines are likely to be in series during part of the time of synchronization.

The instrument connections of a three phase 440 volt switchboard for parallel operation of two ma/

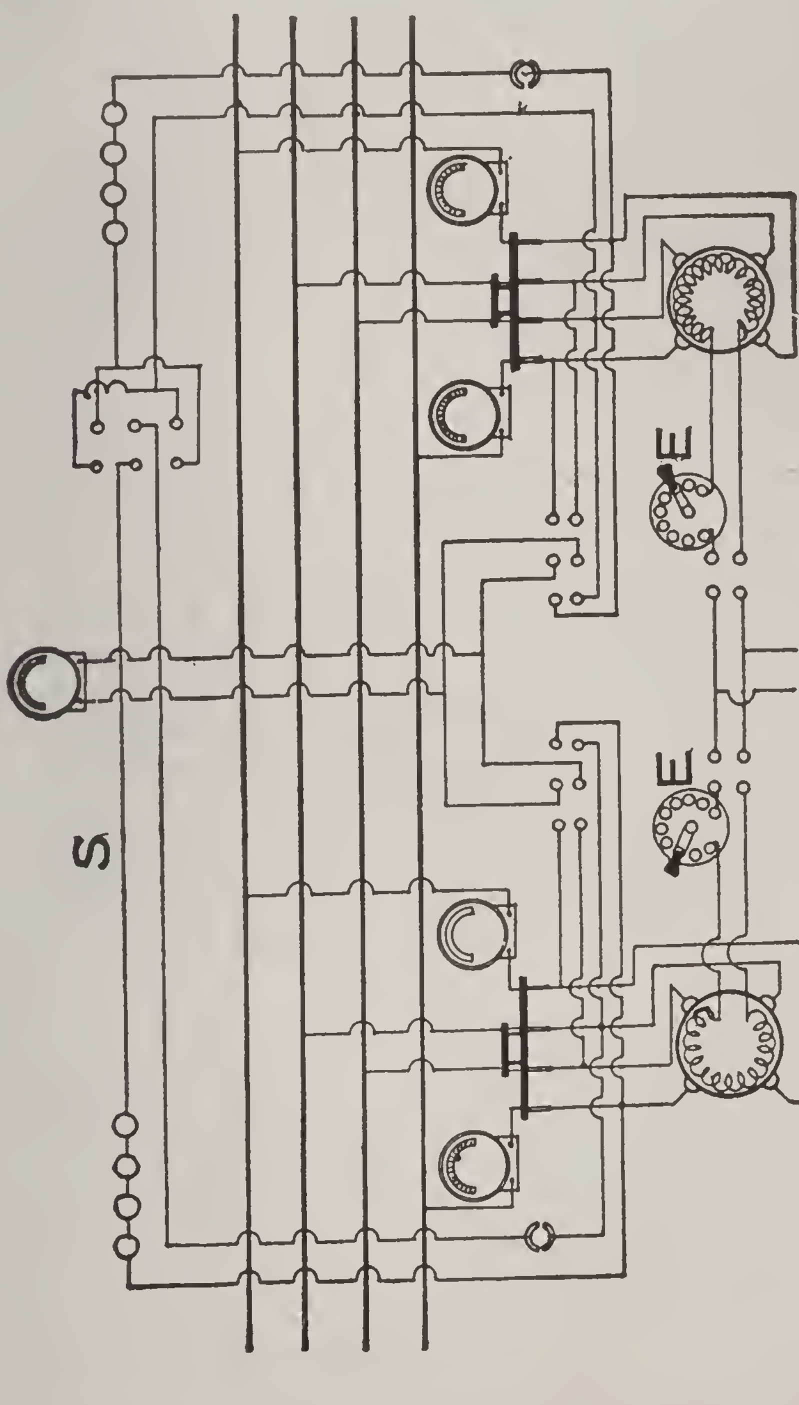


FIGURE 148f.

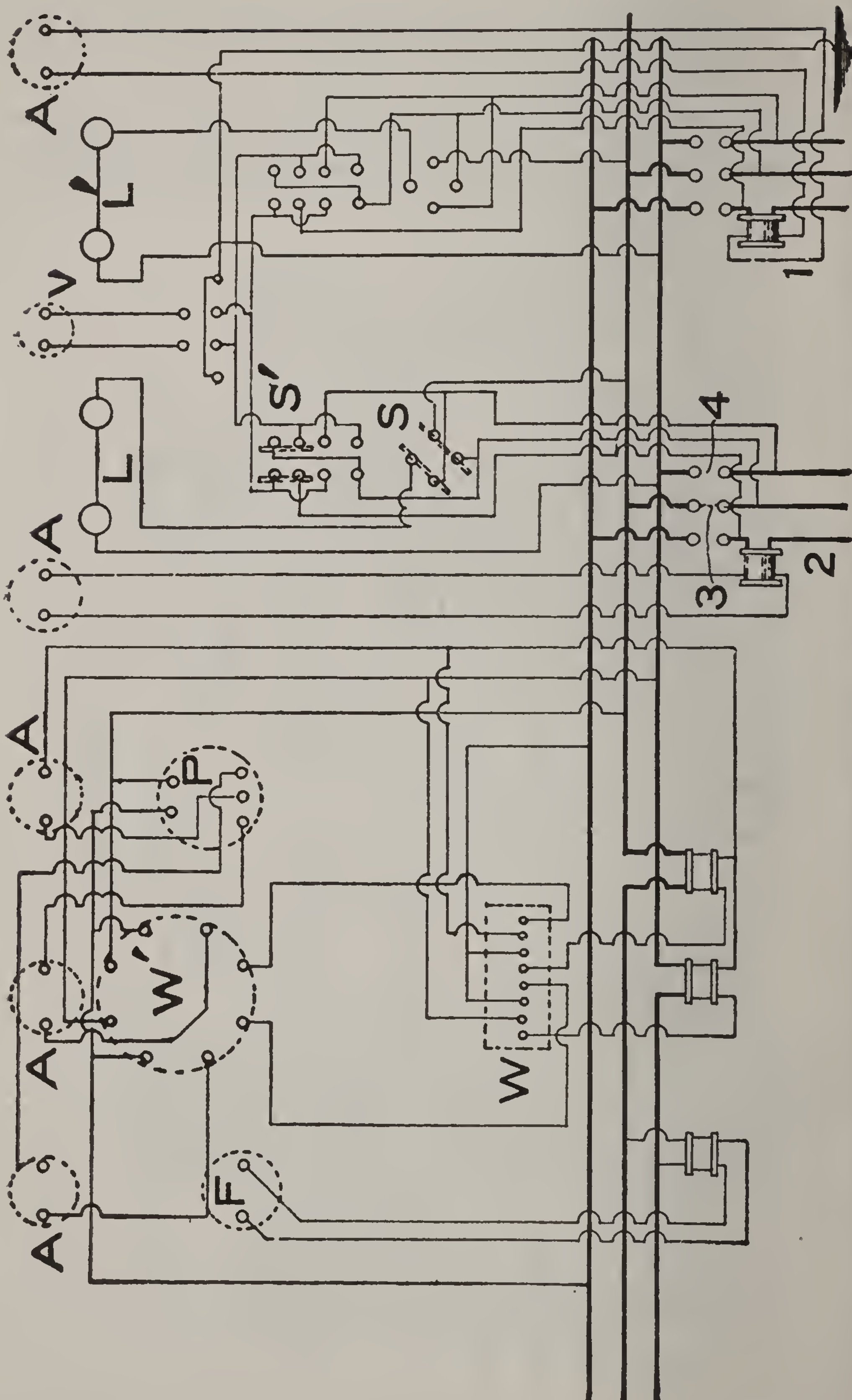


FIGURE 148c.

chines are given in Figure 148g. To avoid confusion the exciter circuits and those leading to lamps and motors are omitted.

An ammeter is provided for eaeh machine by which it can be determined whether it is taking its share of the load. There is further an ammeter in each phase of the bus bars to indicate the balance maintained on the system.

W is a recording watt meter; W′ an indicating watt meter; P a power factor meter, and F a frequency meter. (See Figure 154s.)

L and L′ are the synchronizing lamps, two of which are provided for each machine. To synchronize machine 2 with 1 which is already running, the plug is inserted as at S, the lower half of the plug closes gap 3 and the upper half closes gap 4 through the lamps L. If the machines are not in synchronism the lamps will alternately be bright and dark. The speed of the incoming machine must be altered until the periods of light and darkness are of several seconds duration. During the middle of the dark period the main switch may be closed and the machines will then operate together.

By tracing out the circuits it can be seen that the plug placed as at S′ by being inserted in the upper, middle, or lower set of contacts can be used to take the reading of either of the three phases on the voltmeter V. The voltmeter is also connected so as to be available as a ground detector.

ARC LAMP CONTROL FOR MOTION PICTURE WORK

Arc lamps used in connection with motion picture machines have caused the construction of some special forms of generators.

Figure 148h shows the connections of an alternating-current to a direct-current motor-generator of the Fort Wayne Electric Company. The switch *A* is used to start it and is shown connected to a three-phase line. Aside from the field winding there are three wires leading to the generator. The wire *B* carries a compound winding inside of the generator which opposes the magnetization of the shunt winding. The wire *C* carries another compound winding which is arranged to strengthen the shunt field. *D* is a box containing two resistances, one for each arc lamp shown.

If only one lamp is to burn, the switch *E* is closed and the arc started in the usual way. When ready to change to the other arc lamp, switch *E* must be opened, the switch on the second arc lamp closed, and the arc struck. Then extinguish the first arc and close the switch *E* again. If both lamps are to be used continually, switch *E* must be left open.

As long as current is used through wire *B*, there is no loss of energy in any resistance and should the current in the arc rise, as when the electrodes are brought together, the increased current in the series winding, cut into this wire, would weaken the field and thus keep the current down. When current is used through the wire *C*, the series field winding strengthens the field and builds up the voltage sufficiently so that the lamps may be operated through the resistances. The field strength may be further regulated by the rheostat *R*.

Another connection of the Fort Wayne motor-generator is shown in Figure 148i. In this case the lamps may be operated either from the compensarc *C* or the generator. By throwing either one of the switches connected to the arc lamps up, the corresponding arc lamp is connected to the compensarc. By throwing the switch down it is fed from the generator. The lamp, by which the picture is being projected, should be fed from the generator and when nearly

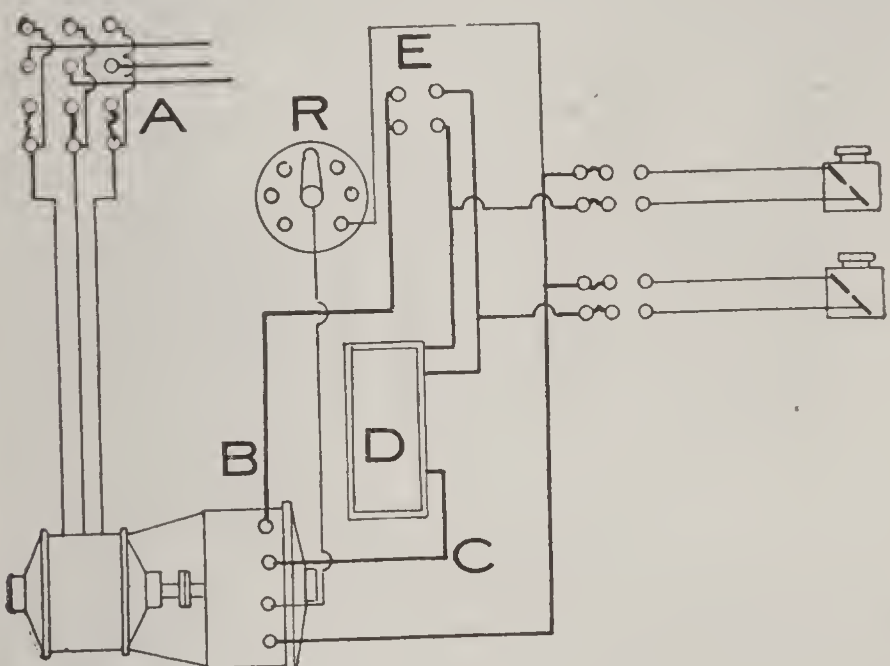


FIGURE 148h.

ready to change, the other may be started on the compensarc. This lamp will burn with a short arc and when it is connected in parallel with the one on the generator, it will immediately extinguish the latter.

Another combination of motor and generator sometimes used is shown in Figure 148j. By tracing out the circuits it will be seen that the armatures of both are in series and that the electrodes, when they come

together, form a shunt about *B*. With the electrodes separated, if current is turned on, it must pass through both armatures in series. Thus the counter e.m.f. of both armatures opposes that of the line and they operate at a certain speed. Each motor has a natural tendency to send current in opposition to that impressed upon it by the line. If then the electrodes are brought together, they at once form a short circuit around the armature of *B*. The current in *B*

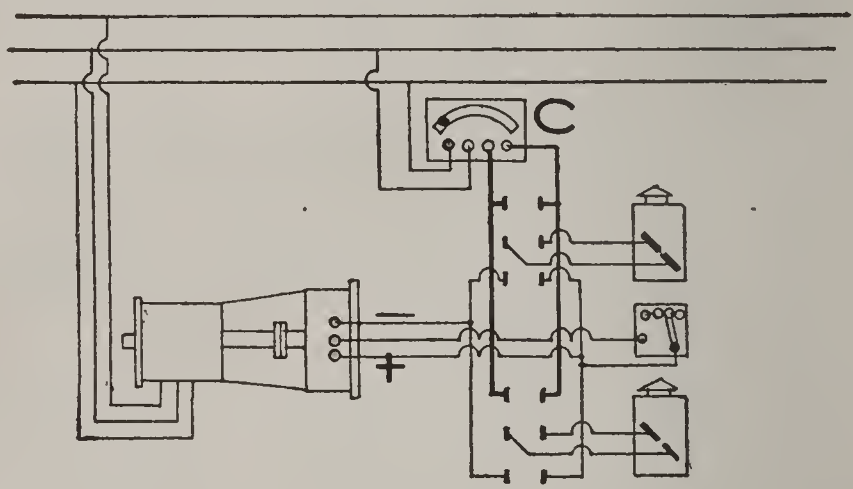


FIGURE 148i.

reverses and it then begins to act as a generator and sends current through the arc lamp. The current which passes through the armature of *A* also passes through the arc lamp. *A* is then a motor and operates *B* as a generator.

The voltage at the arc is less than the line voltage by as much as the counter e.m.f. of motor *A* amounts to, neglecting the drop in voltage due to resistance. No resistance is needed if the winding is properly arranged and there is not the loss in heat which goes with the use of resistances. This arrangement can be used with direct-current circuits only. It is not suitable where the supply voltage is very much higher

than the voltage used at the arc. A field rheostat is provided to adjust the field strength of *B*. *A* is equipped with the ordinary motor-starting rheostat only.

Rotary Converter Control.—This is a machine used only where the supply is alternating current. The voltage delivered to the converter must be the same as that desired at the direct-current terminals. This machine has an armature essentially similar to that of a direct-current dynamo. Alternating current is supplied to it at one set of terminals and direct cur-

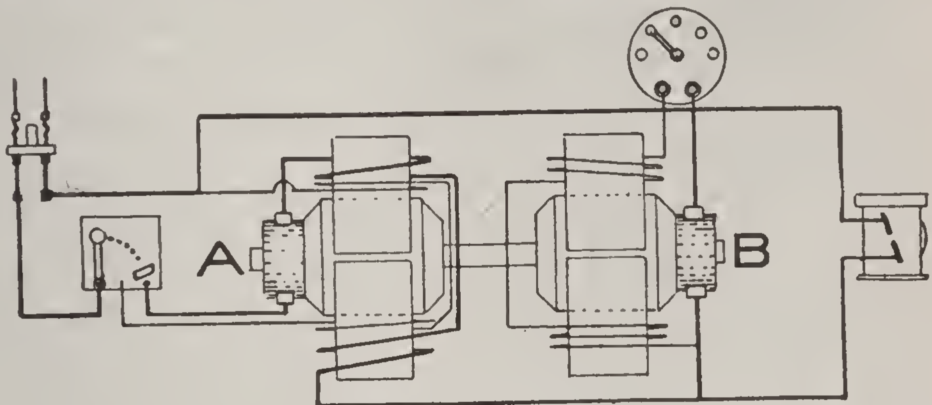


FIGURE 148j.

rent is taken from the others. This armature acts as motor and generator at the same time. Whatever voltage regulating is necessary with this machine must be done on the alternating-current side. Changing the field strength does not materially affect the voltage so that no means for regulating the field strength is provided.

The polarity of the direct-current terminals depends upon the position the armature happens to be in when the alternating current is applied to it and is very apt to come in wrong when the machine is started. It is therefore necessary to have a polarity indicating voltmeter in the circuit and to watch it when starting the machine. If the polarity is wrong,

the switch must be opened and in a moment thrown in again; and if still wrong, this process must be repeated until the polarity comes right. Each arc lamp fed from a converter must be equipped with resistance.

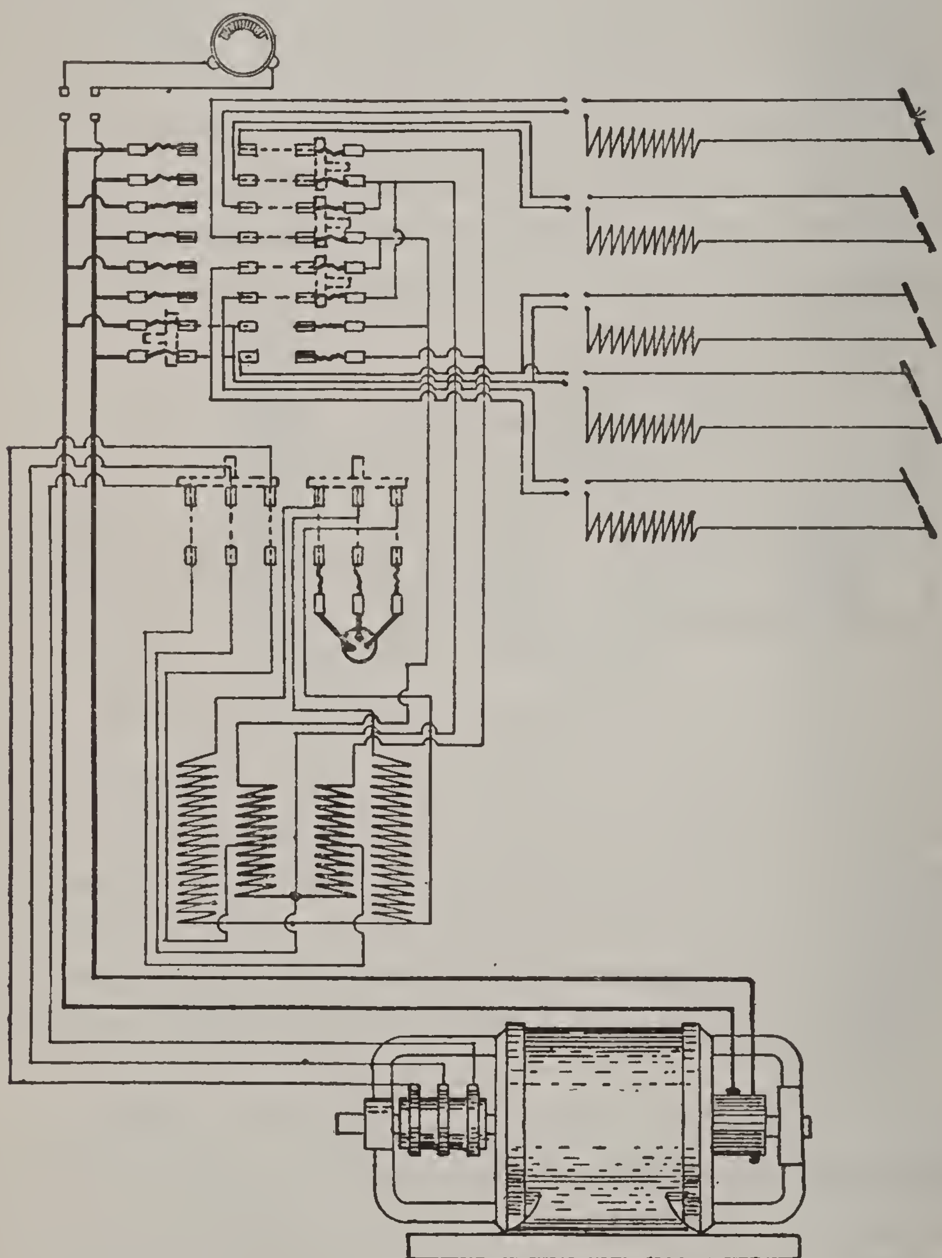


FIGURE 148k.

The Martin rotary converter is especially designed for motion-picture work and may be provided with the proper connections for either single-phase, two-

phase, or three-phase work. There is a stator ring which entirely surrounds the armature. This ring is made up of laminated disks with squirrel-cage bars and slots alternating. The squirrel-cage bars are joined at the end to a copper bar and it is by the aid of this squirrel-cage that the motor may be started and brought into step. The squirrel-cage also prevents "hunting" which is one of the common troubles experienced with synchronous motors or converters. Into the slots are wound special compensating coils to balance the armature reaction and keep the neutral point in constant position from no load to full load. This prevents sparking at the brushes. On the outside of this damper ring or squirrel-cage winding is the regular shunt-field winding used with direct-current motors or generators.

Figure 148k is a diagram showing the connections of the Martin Rotary Converter as installed by the Northwestern Electric Company of Chicago. This switchboard is equipped to operate two moving-picture arcs, two dissolving stereopticon lamps, and one spot light. Each lamp is provided with a throw-over switch so that current may be used, either from the alternating-current mains direct or from the direct-current side of the converter.

Figure 148l is another panel board for moving-picture work made up by the same company. In this case resistances are provided for use when the arc lamps are operated from the converter. In case it is desired to run from the alternating-current mains, transformers or compensarcs are used. The emergency feature of these panel boards is highly to be recommended. It must be borne in mind that one may suddenly be forced to deal with an operator who

has never seen a converter and knows nothing of its operation; and there is also always the possibility of some trouble with the machine.

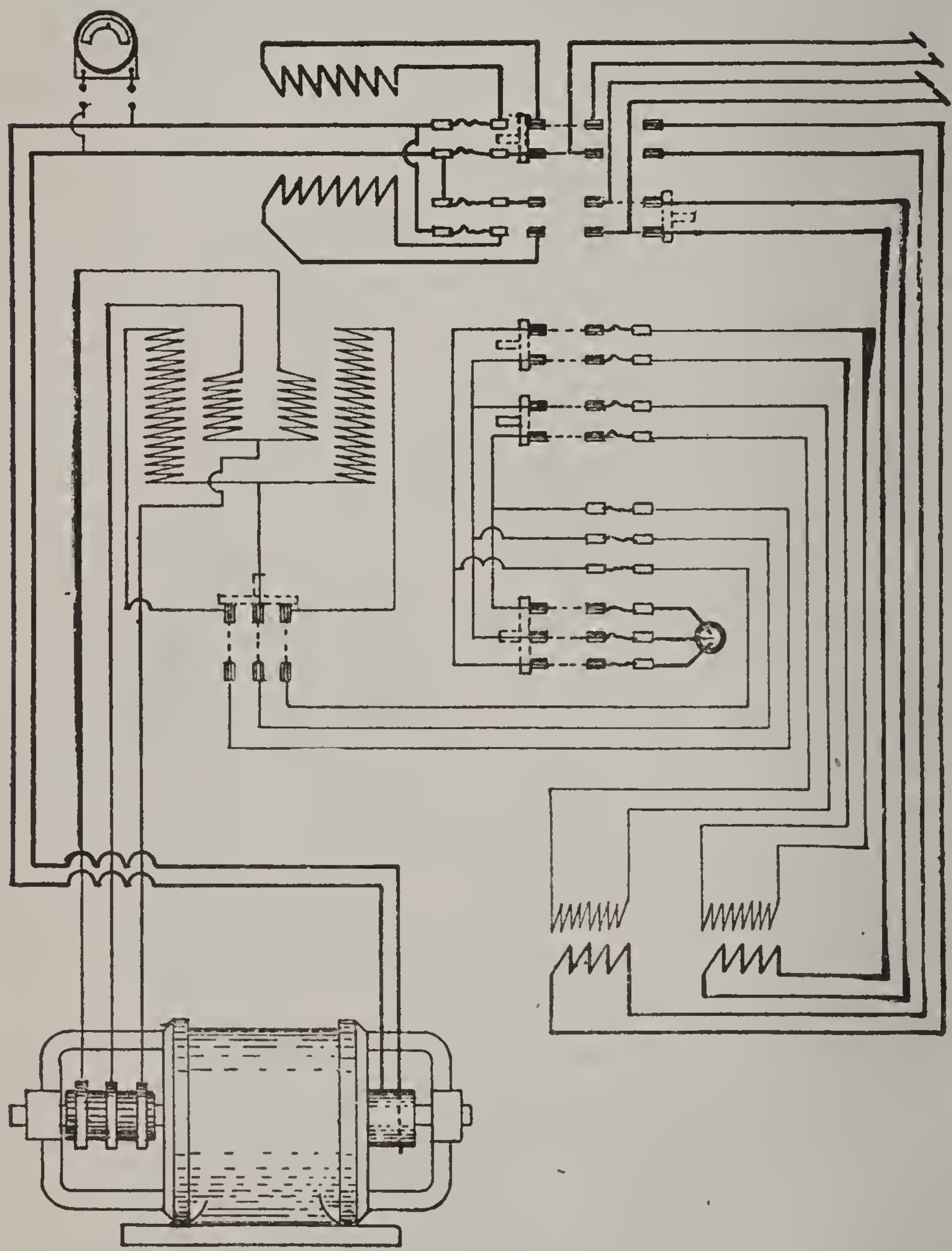


FIGURE 148l.

A Martin rotary converter to be operated from a single-phase line is shown in Figure 148m. This machine is started through the commutator side. In

order to start this machine it is necessary first to close the main switch. Next throw the switch *2* to the right and leave it there for about five seconds. It may then be thrown over to the running position at the left and allowed to remain in this position. If

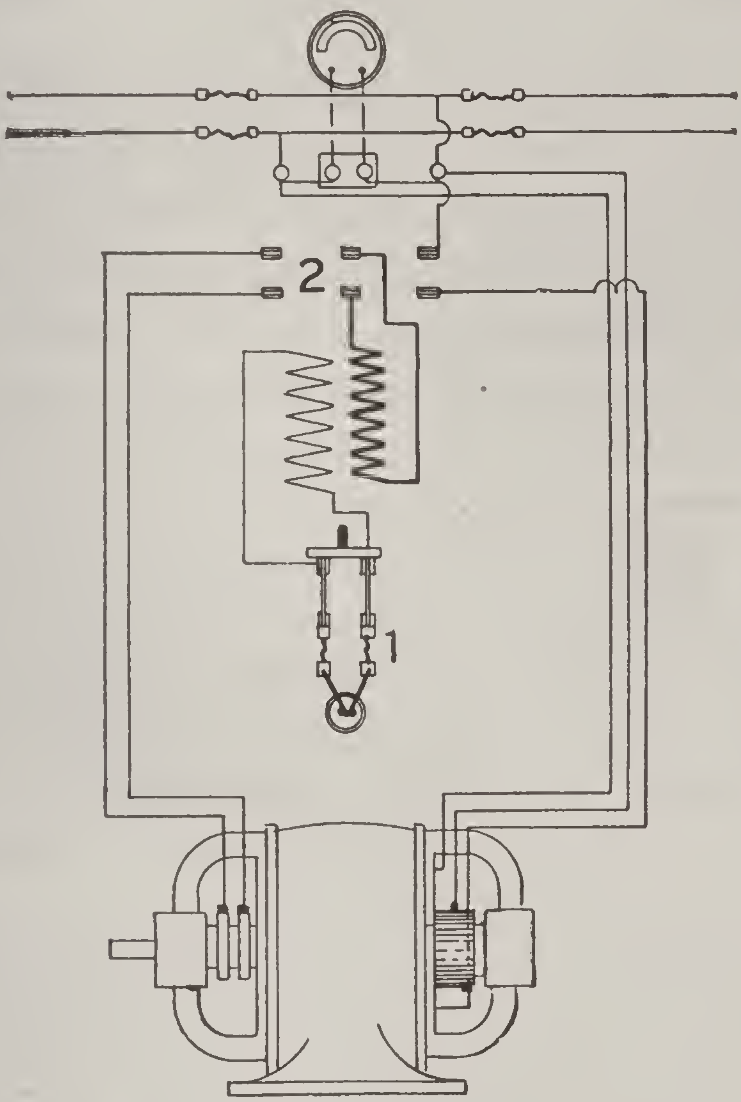


FIGURE 148m.

the polarity is not correct, the switch must be opened again for an instant and closed again; and this process must be repeated until the polarity comes in right. To stop the converter, first open the main switch and then the throw-over switch.

CHAPTER XV.

ALTERNATING CURRENT MOTORS. TRANSFORMERS.

There are two general classes of alternating-current motors, known respectively as "synchronous" and "induction" motors. As an example of the first class: If two identical alternating-current dynamos are connected together by wires, one running as a generator and the other as a motor, the driven machine would run at the same speed as the driving machine; for, at every change in the direction and strength of the current given out by the generator, like changes would be produced in the machine running as a motor. They would then run in synchronism. It may be advisable to state here that the machine running as a motor would first have to be brought up to speed, as the majority of synchronous motors are not self-starting.

When a multiphase (2 or 3-phase) alternating current is sent around the fields of an alternating current motor, a revolving field is set up in the space occupied by the armature. If now an armature of what is known as the squirrel cage type (a laminated armature in which bars of copper, running parallel to the shaft, are imbedded in slots in the periphery, the ends of all the bars being connected together,

(Figure 149), is placed in this field, currents will be induced in it which, acting in conjunction with the revolving field, will cause the armature to turn. These are known as induction motors, and this class is generally employed in commercial work. Such motors will start themselves from rest with a considerable torque, and will stand a reasonable amount of overload.

The direction of rotation of motors of this kind is reversed by changing the relative position of wires in any phase. It can readily be seen that this will cause the revolving field to move in the opposite direction.

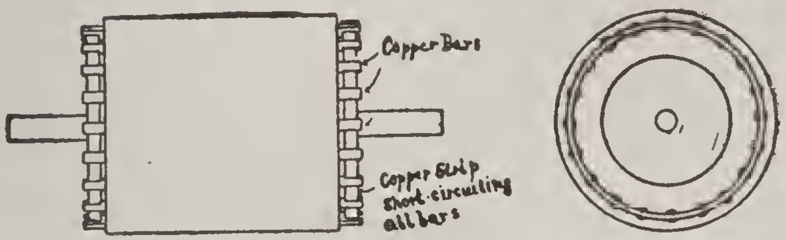


FIGURE 149.

The action of the current in the starting of induction motors is very similar to that in direct-current motors in that if, while the motor is at rest, the current was thrown directly on, it would rise to a considerable value. The smaller size motors may be directly connected to the circuit as is often done with direct current motors but with the larger size motors some device must be used to keep down the excessive current on starting.

Resistance boxes may be inserted in the motor circuits and operated in the same way as on direct current apparatus the resistance reducing the voltage at the motor terminals. On two and three-phase work resistances must be inserted in each phase and arranged to work together so that the changes in pressure at the motor terminals will be the same.

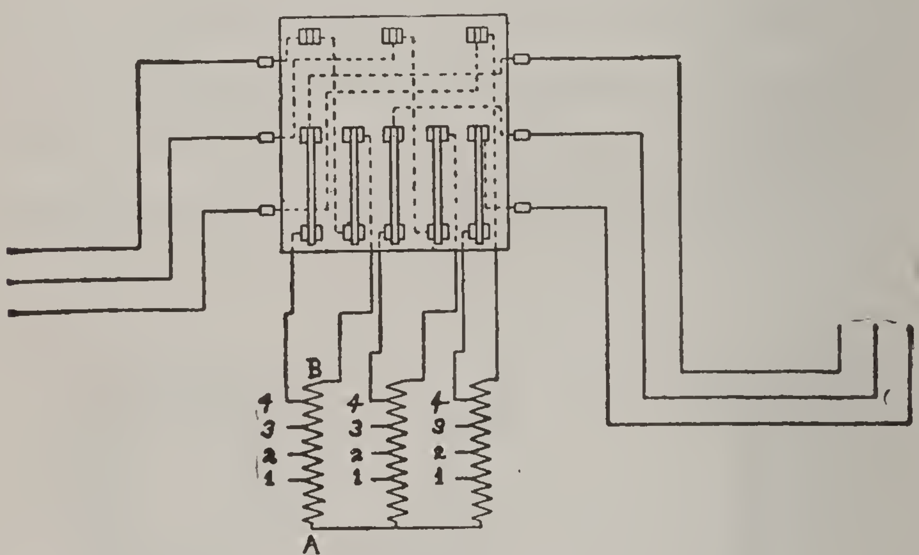


FIGURE 150.

Figure 150 shows the connections of the General Electric Company's compensator used in starting three-phase motors. This apparatus consists of three coils wound on laminated iron cores forming an auto-transformer in which one wire is used for both primary and secondary, and works on the principle that, if an alternate current is sent through a coil of wire, and a tap taken from some intermediate point in the winding, the voltage between the tap and the end of the coil will be less than the full voltage sup-

plied, depending on the position at which the tap is taken off. In the diagram suppose that the difference of potential between the terminals A and B were 115 volts; then the difference of potential between A and 4 would be less than 115, while the difference of potential between A and 3 would be less than between A and 4. To start the motor the switch is thrown to the lower position, when the motor will receive the reduced current due to the reduced voltage between A and 4. When the motor is up to speed the switch is thrown to the "up" position, when the motor will receive the full voltage of the line. If more current is required in starting than can be obtained with the connection at 1 (this being the point of lowest voltage), connection can be made at either 2, 3 or 4 until the current required to start the motor is obtained. Were the motor, while at rest, thrown directly onto the mains without the use of the compensator, the current would rise to six or seven times that normally required; while in starting with the compensator the current varies from full load to about twice full load current according to whether connection is made at 1 or 4.

Another method used in starting alternating current motors is shown by the diagrams in Figure 151. The upper diagram shows the connections on a three-phase armature where one end of each coil is connected to a common wire, the other ends of the coils being carried to contact shoes *2*, *2*, *2*. Between the contact

shoes *2*, *2*, *2* and *1*, *1*, *1* are connected resistance wires, these wires ending in a connection common to them all. When the motor is started current flowing from the armature coils passes through the resistances *r* and *s*. This is shown in the lower left hand diagram. As the motor speeds up the contact

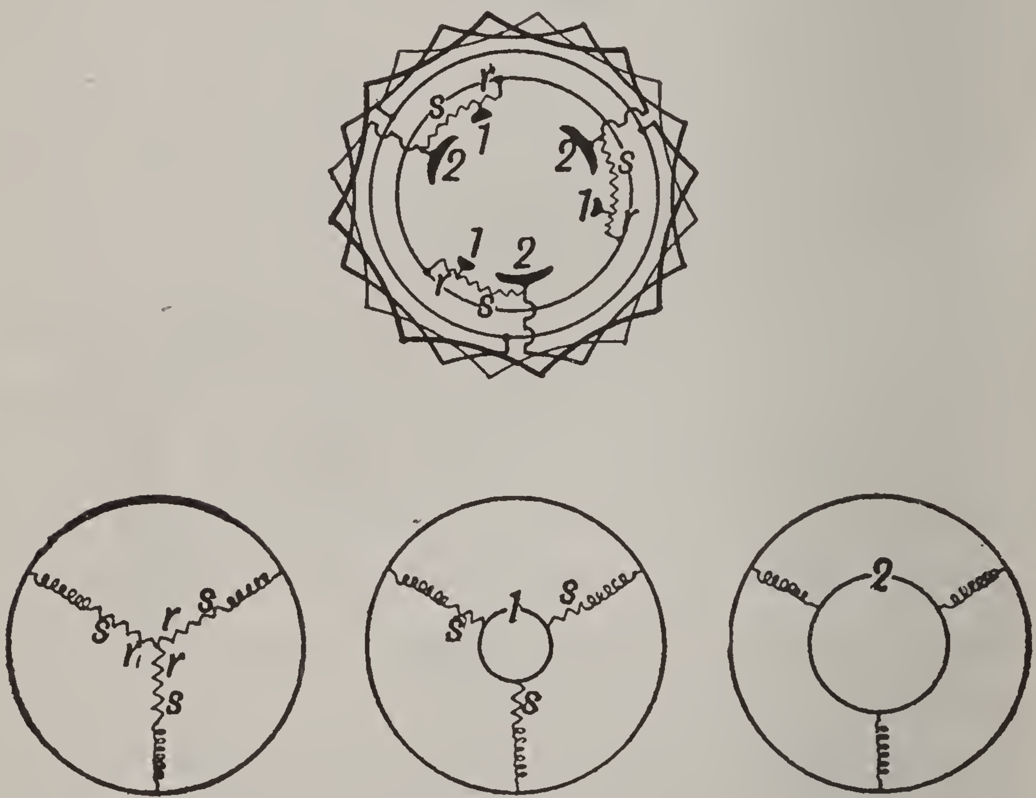


FIGURE 151.

shoes *1*, *1*, *1* are short-circuited, thus short-circuiting the resistances *r*, *r*, *r* as shown in the middle diagram. As the speed further increases the contact shoes *2*, *2*, *2* are short-circuited, this in turn short-circuiting the resistances *s*, *s*, *s*. The motor will now run with no resistance in the armature circuit as shown in the diagram at the right.

Figure 152 shows the connections for the Wagner single-phase alternating-current motor. On top of the motor are three binding posts. Posts 1 and 3 are connected to the terminals of the field winding,

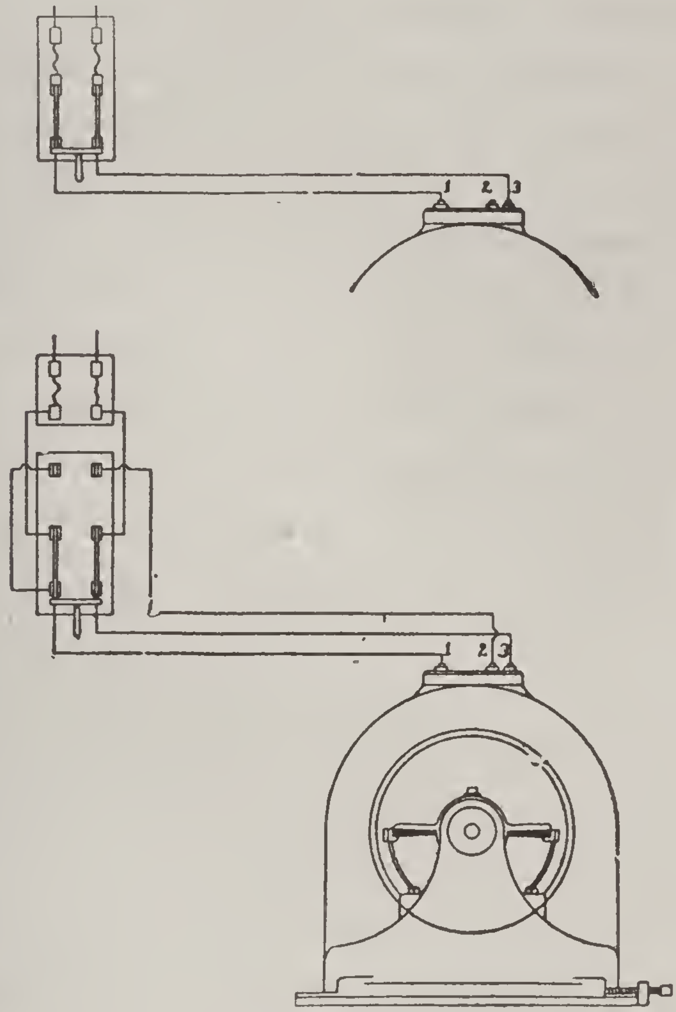


FIGURE 152.

while post 2 is connected to an intermediate point between 1 and 3. When the motor is called upon to start a heavy load, the double-throw switch shown in the lower diagram is used. With the switch thrown to the upper position connection is made to posts 1

and 2, when, on account of part of the field winding being cut out, a greater amount of current is sent through the fields and the torque increased. When the motor is up to speed the switch is thrown to the lower position, where current will be sent through the entire field winding.

The armature winding consists of a number of copper bars terminating in a commutator at one end. While running up to speed the armature is short-circuited through brushes which bear on the commutator and produce in the armature poles which, acting with the fields, cause the armature to revolve. On attaining full speed an automatic governor mounted on the shaft lifts the brushes off the commutator, and at the same time short-circuits all the commutator bars. The motor now runs as an induction motor. The upper connections are used where an ordinary load is to be started.

This motor is reversed by moving the brushes on the commutator. Note the markings on the brush holder. The starting torque can also be varied by shifting the brushes. It will be greater as the mark on the brush holder is moved farther from the center mark.

Single-phase motors, unlike the multiphase motors, will not start themselves from rest without the provision of some special means. A number of different methods are in use to make these motors self-starting. In the small fan motors made by the General Electric

Co. the ends of the pole pieces are slotted, and around one of the projecting ends is placed a band of copper (Figure 153). The effect of this band of copper is to cause two magnetic fields under each pole piece, one being slightly out of step with the other. This has an effect on the armature similar to a two-phase current, and causes it to revolve.

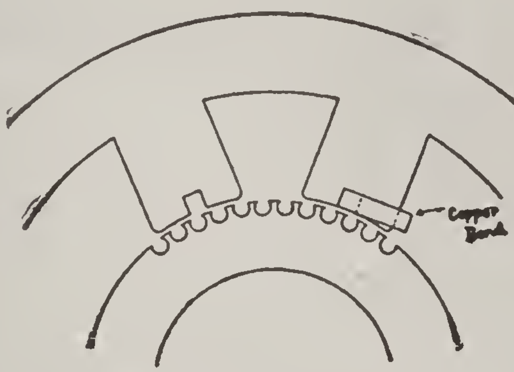


FIGURE 153.

Another method, known as the "split phase," is used for the same purpose. In some of the smaller motors made by the Holtzer-Cabot Co. the field is wound with two separate coils, one having a few turns of comparatively large wire and the other a great number of turns of fine wire. When current is turned on, owing to the difference in self-induction of the two coils, a field similar to the two-phase field is set up and the armature caused to revolve. When the motor has reached synchronism, the current to the high resistance coil is opened and the motor operated on the low resistance coil alone.

Other methods of bringing single-phase motors up to speed are described in Figures 154 and 152. Any small direct-current series motor can be used on alternating current providing the field magnets are laminated. The larger motors generally contain too much self-induction to be operated on alternating current.

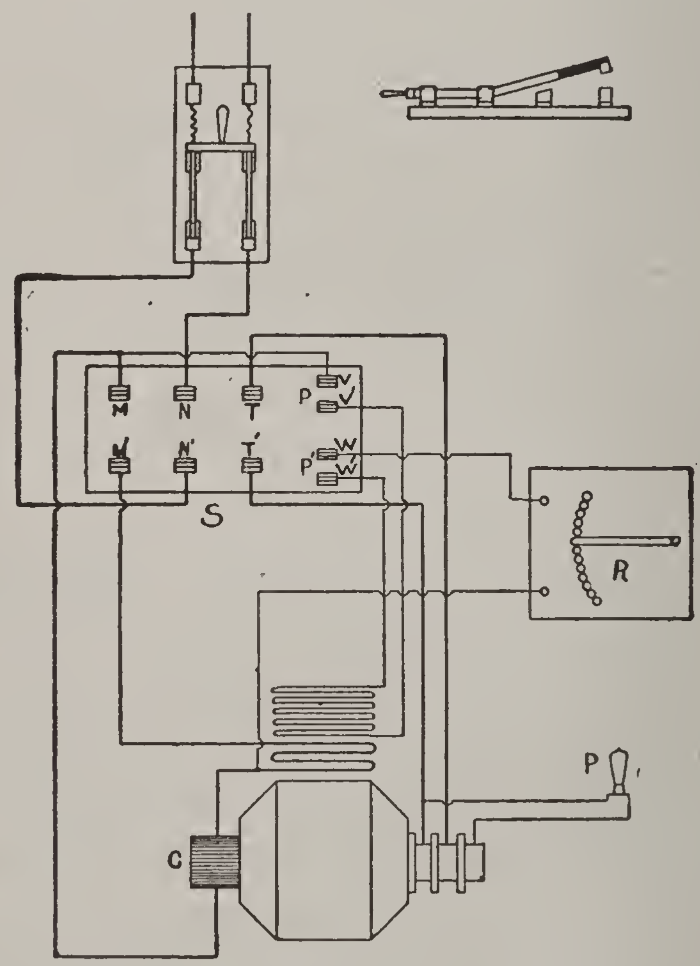


FIGURE 154.

Figure 154 shows the connections of the Fort Wayne alternating-current, single-phase motor. In order to start this motor and bring it up to speed,

the armature is provided with an extra winding connected to the commutator C, shown at the left. When the motor is to be started, the switch S, which is hinged at N, N′, is closed to the left. Current from the left-hand main will then pass through the contacts N′, M′, on the switch S to the series winding, and then to the commutator and armature and out through M, N, on switch, to other side of line. At each reversal of the current the magnetism in both fields and armature is reversed at the same time, thus causing a steady pull in one direction on the armature.

As the motor comes to speed the pilot lamp P will gradually light up, and when it has reached full candlepower the switch S is thrown to the right. Current from the left-hand main will now pass through contacts N′, T′, on switch, to the collector rings, through the armature, and out through points T, N, on switch to other side of line. At the same time the contacts V, V′ and W, W′ on switch S will be short-circuited (these points of the switch are not in electrical connection with the blades, being separated therefrom by an insulator, as shown in figure in upper right-hand corner), and the shunt field circuit closed through the commutator; the direct current from the commutator passing from the lower brush through the points V, V′, on switch, to the shunt field and back to points W, W′, and through the rheostat R to the upper brush on commutator. The motor will now run as a synchronous motor, the

armature receiving current from the mains, while the field is energized by means of the direct current generated in the extra winding in connection with commutator C. When the motor is running with the switch to the right the series field is open.

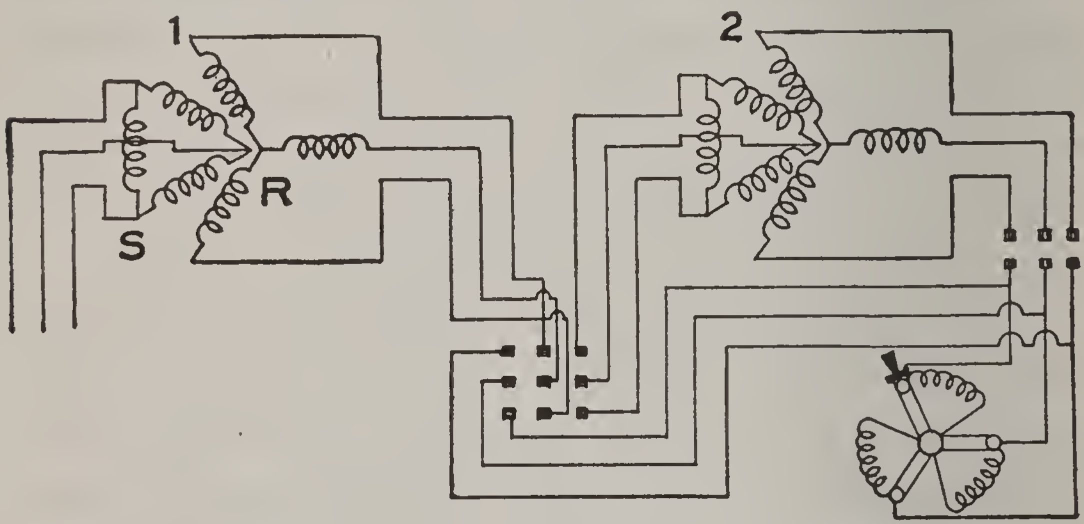


FIGURE 154a.

Figure 154a shows theoretical diagram of what is termed the cascade or tandem method of coupling induction motors for variable speeds. The rotors of the two motors are mounted on the same shaft or in other manner mechanically coupled together. The main current from the generator feeds stator S of 1. The currents induced in the rotor R of 1 traverse the stator of 2 and the controlling resistance is cut into the rotor circuit of 2 as shown.

The number of poles on two such machines may be so arranged that different changes in speed are possible. It is also possible to arrange switches so that the

motors may be operated in parallel or No. 1 alone as shown.

Figure 154b shows method of operating rolling mills or other devices that require a large amount of power for a very short time. The large induction motor I

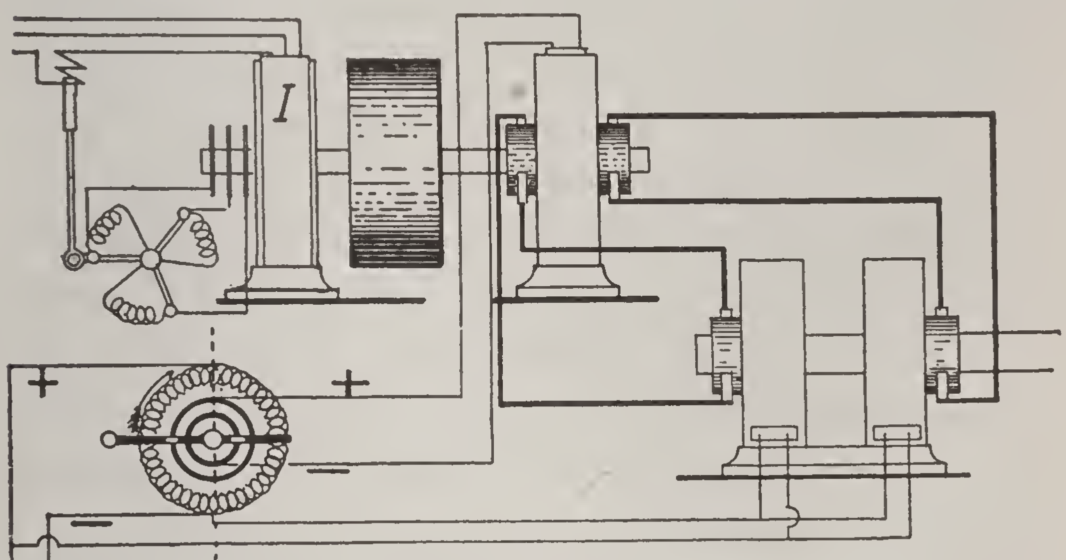


FIGURE 154b.

is supplied by a limited amount of current from the mains. The amount of current that may be drawn from the mains is governed by an automatically controlled resistance placed in the rotor circuit. Whenever the main current rises above a predetermined value the core of the solenoid is drawn up and resistance is cut into the rotor circuit, thus keeping the main current in bounds.

On the same shaft with the induction motor is a heavy balance wheel operating at a high speed and also the armature of a direct current generator. This generator carries a double wound armature which

feeds two motors connected to the shaft of the rolling mill.

The only method of reversing and controlling the speed of the motors consists in changing the field strength of the generator. The fields of the generator are separately excited and controlled by resistances arranged similar to those of the well known Wheatstone bridge. With the arm in the position shown no current is passing through the fields. If the arm is moved in the direction of the arrow the polarity of the fields will be as indicated, and when the arm assumes the position indicated by broken line the current strength will be at its maximum. If it is moved in the opposite direction the current in the generator fields will be reversed.

The motors are also independently excited and the direction in which they move depends upon the direction of the armature current, which in turn is governed by the current through the fields. With this arrangement it is possible to draw 4000 or 5000 H. P. for a short time without overloading the 1000 H. P. induction motor.

Very small alternating current motors are usually connected to the line direct, and only a switch suited to the system is used. This switch does not even require to break all of the wires of the system.

As the starting current of most alternating current motors is, however, much greater than the running current (especially if the motor start under load) it is

advisable to place the motor under the protection of two sets of fuses. One such set of fuses is placed where the branch circuit is tapped off the mains, and the other at the motor switch.

The manner of connecting a throwover switch to two and three phase motors so as to accomplish the desired result is shown in Figures 154c and 154d.

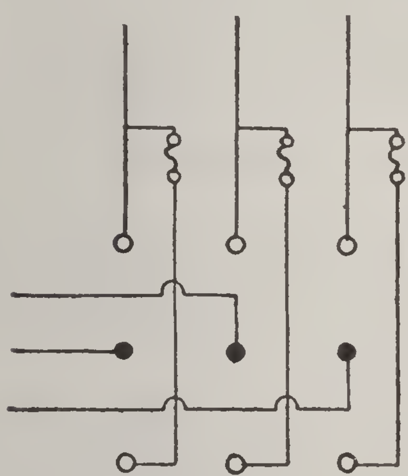


FIGURE 154c.

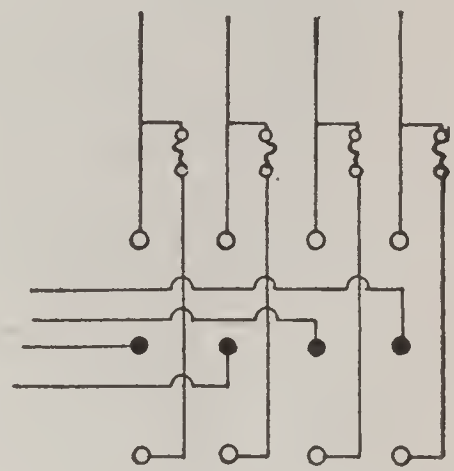


FIGURE 154d.

The black circles represent the centers of the switch. Thrown upward the motor feeds direct from the mains which are fused to the starting current of the motor. After the motor has acquired its proper speed the switch is thrown downward and the motor feeds through the smaller fuses shown.

In order to guard against leaving the motor without the proper fuse protection such switches are sometimes equipped with springs which will not allow the switch to remain on the upper contacts.

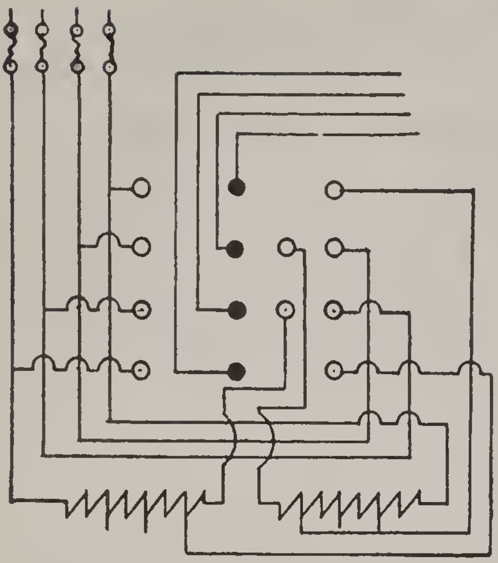


FIGURE 154e.

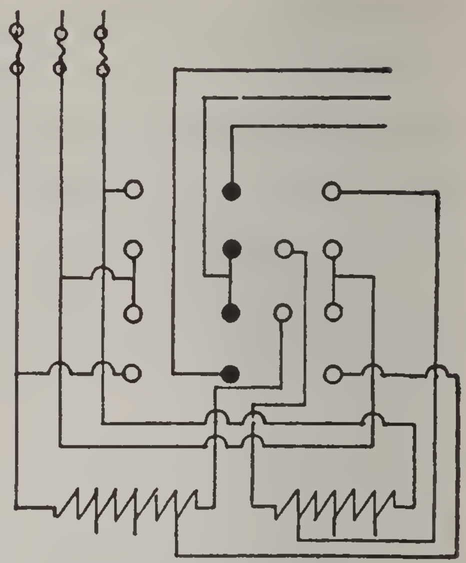


FIGURE 154f.

Throwover switches for the starting of motors in connection with auto transformers or compensators are shown in Figures 154e and 154f.

To start, the switch is thrown to the right; this forces the current to pass through the transformers and reduces the voltage at the motor. After the motor has attained some speed the switch is thrown to the

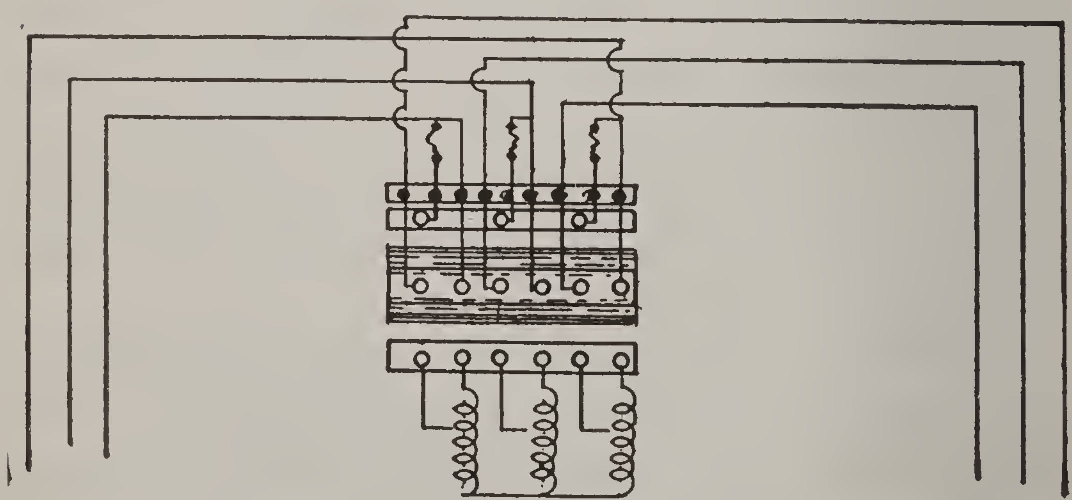


FIGURE 154g.

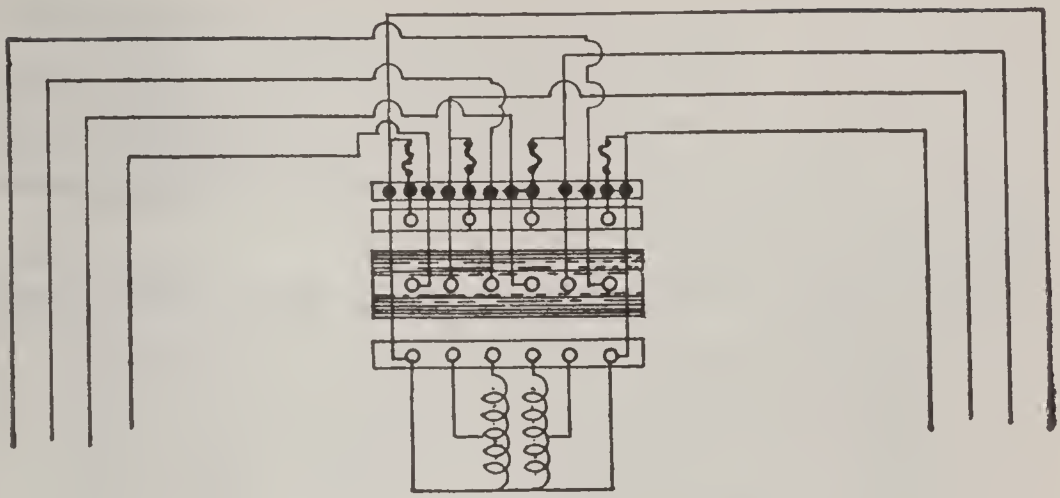


FIGURE 154h.

left and connects the motor to the mains. The starting torque of the motor may be increased by connecting the taps leading from the transformers so as to leave less of their reactance in the circuit.

The connections of General Electric controllers for three phase; two phase four wire and two phase three wire are shown respectively in Figures 154g, 154h, and 154i. The contact points on the drums in the center make connections either to the upper or lower

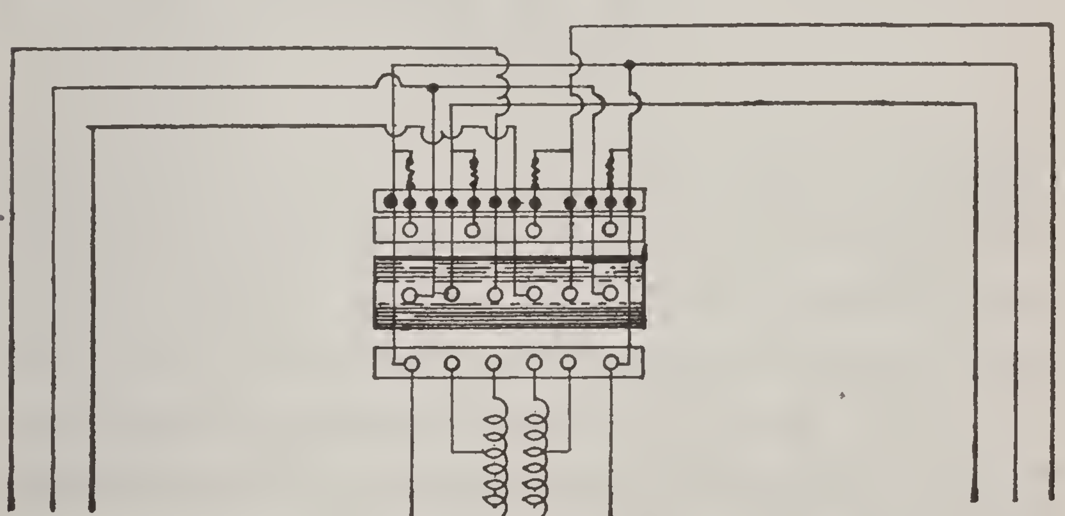


FIGURE 154i.

connections shown. The motor leads are connected to the drum. Thrown downward the current must pass through the auto transformers which reduces the voltage. Thrown upward the motor is connected direct to the mains.

Figure 154j shows diagram of a three phase auto

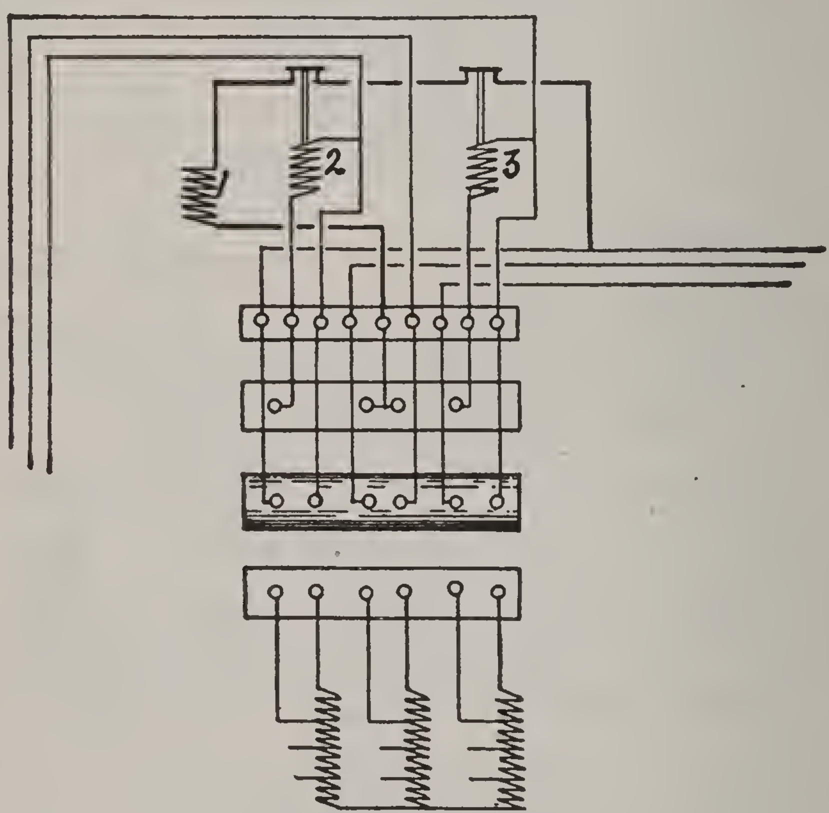


FIGURE 154j.

starter with over and under load release as made by the General Electric Co. In order that the starter may remain in circuit there must be current in coil 1. Consequently when the voltage fails the starter opens the circuit. In case the motor is taking too much current one of the coils 2 or 3 opens the circuit through 1, and trips the starter thus opening the circuit.

A similar arrangement is shown in Figure 154k, but is designed for high voltages and a voltage transformer is provided as shown.

With large motors the wiring is arranged as in Figure 154l.

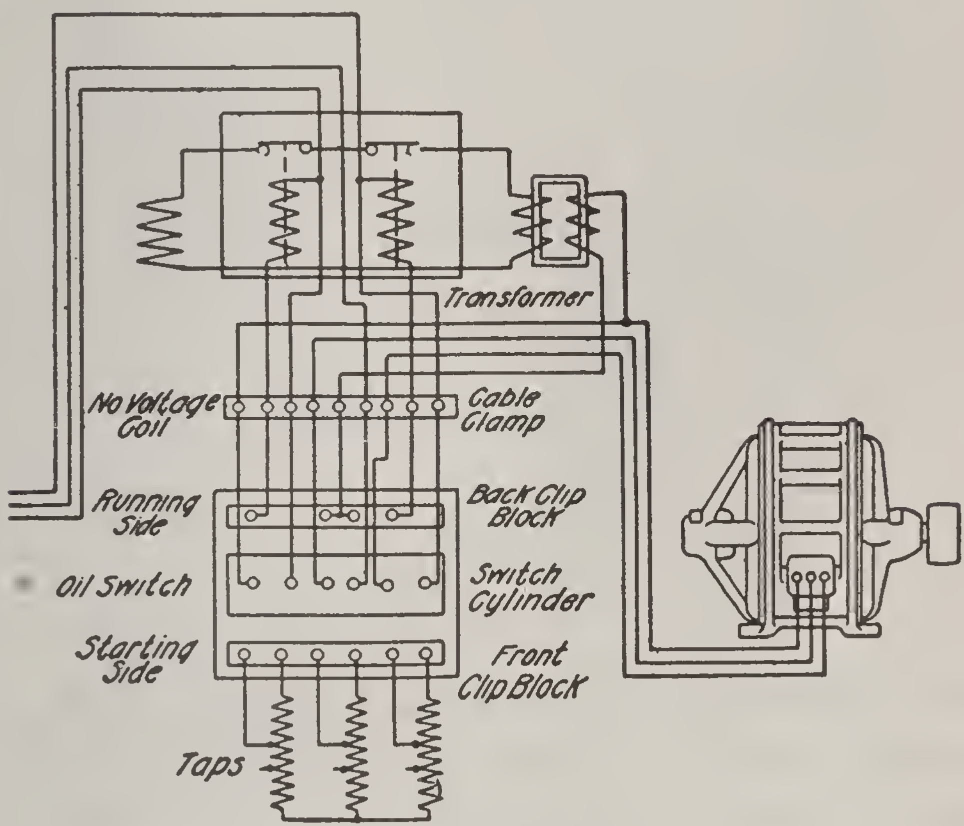


FIGURE 154k.

For motors that start under light load and require finer gradations in speed a controller as diagramatically shown in Figure 154m is often used. The compensator coils are inserted in two phases only; this results in unbalancing of the line but as long as the load is light this is not very objectionable.

The speed of a three phase motor is considerably higher when its stator is connected in "mesh" or

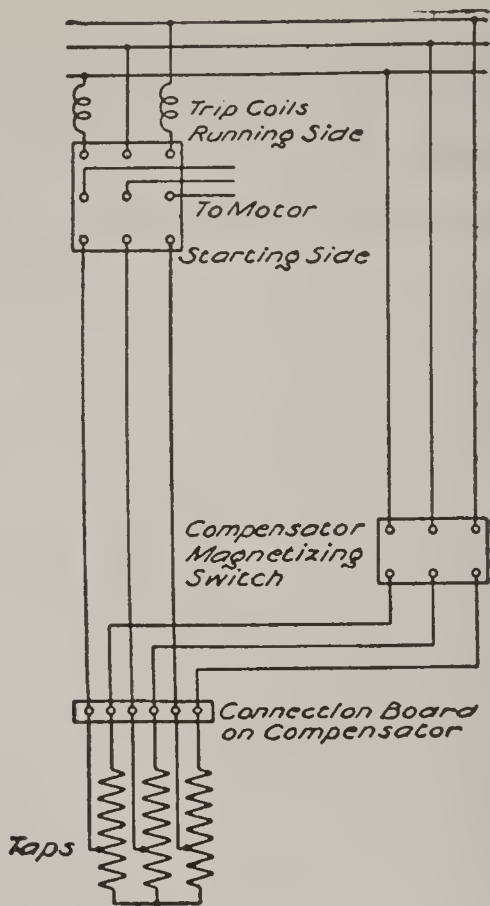


FIGURE 154l.

"delta" than when connected in Y or star. In Figure 154n the throwover switch at the left is provided to change the winding from one to the other when required. Thrown to the left the motor windings become star; thrown to the right they are delta. Motors must not be changed from star to delta unless it is known they are capable of running that way.

A method of obtaining reduced voltage for the starting of three phase motors direct from transformers is given in Figure 154n. Thrown one way the motor obtains the full voltage of the line, and thrown the other way only about one half.

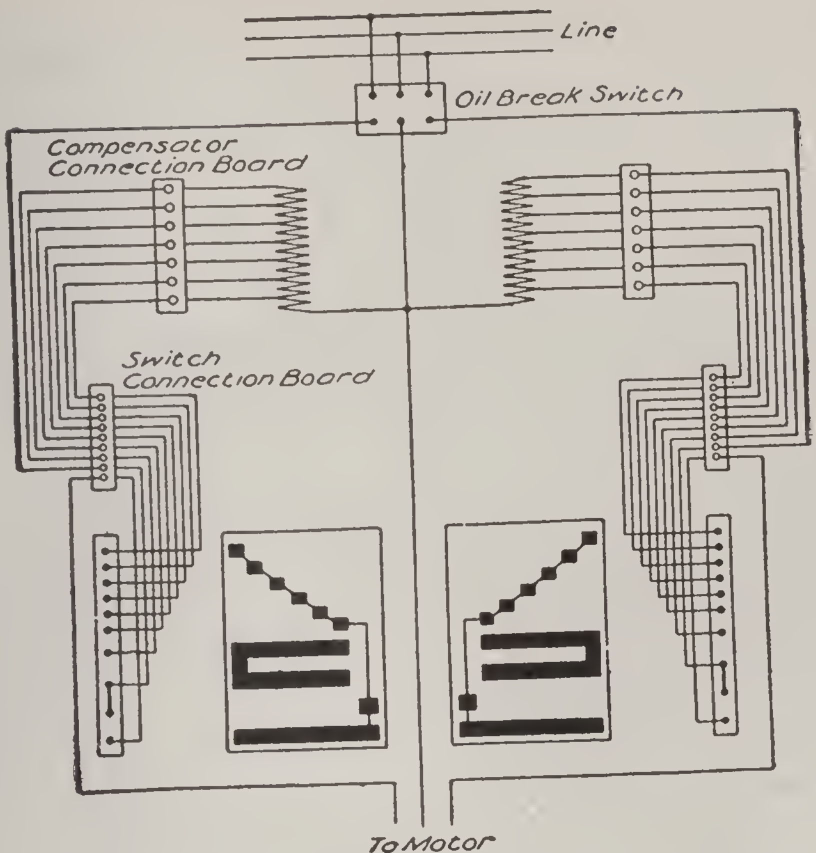


FIGURE 154m.

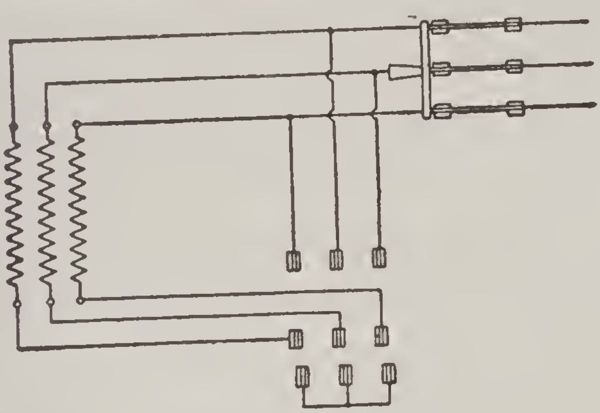


FIGURE 154n.

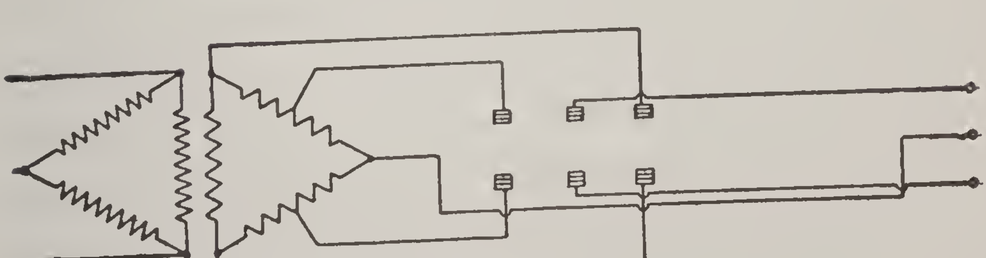


FIGURE 154o.

Two and three phase motors are often equipped with wound armatures or rotors. In such cases the starting can be controlled by resistances placed in the rotor circuit about in the same way that it is placed in the armature circuit of direct current motors. Such resistances are also made variable and are illustrated in Figure 154p for three phase and Figure 154q for two phase.

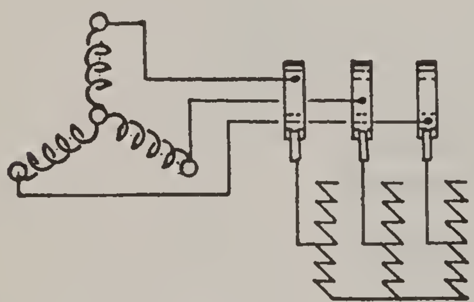


FIGURE 154p.

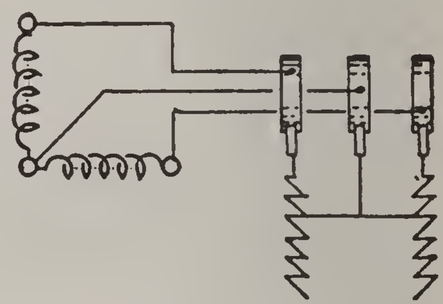


FIGURE 154q.

The rotor of an induction motor acts like the secondary winding of a transformer, but as the rotor comes up to its proper speed the currents in it are much reduced.

Small and medium size motors are sometimes connected to three phase systems as shown in Figure 154r. This is known as the open delta method. Only two transformers are required whereas to get the full three phase connection three would be necessary.

Figure 154s shows the diagram of an automatic controller for three phase motor as made by Cutler Hammer Co. The controller is operated by a single pole switch placed as at P, or, if the circuit be permanently closed at this point, closing of the main switch

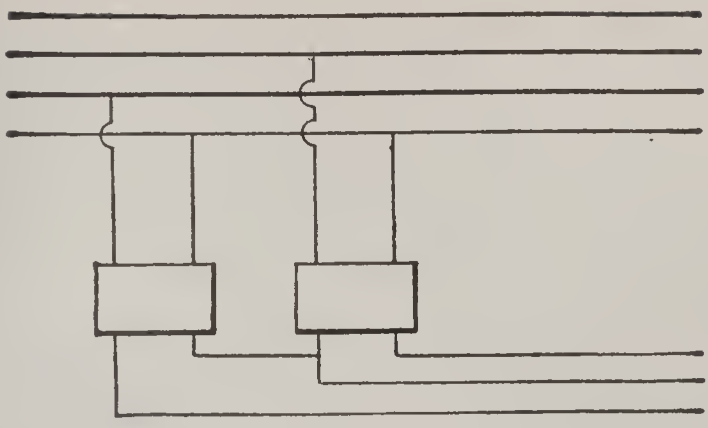


FIGURE 154r.

will automatically start the motor. 1, 2, 3 and 4 are solenoids which when energized draw up their cores and close the circuits indicated underneath.

Solenoid 1 simply closes the phase wires A and B and thereby gives current to the stator windings of the motor M. 2, 3, and 4 when energized short circuit certain parts of the resistance R which is inserted in the rotor circuit. The three small solenoids 5 must be conceived as attached to the extremity of R at 5′; 6 is attached to 6′ and 7 and 8 at corresponding points of R, but only when the solenoids shown above them act. The solenoids are supposed to act in quick succession in the order 1, 2, 3, 4; 4 when it acts finally short circuits the rotor at 8′ cutting all of R out.

The operation is as follows: By closing the pilot switch P circuit is established from phase wire A through solenoid 1 line C point D pilot switch and phase wire B. There is also a parallel circuit through X. Thus energizing 1 causes its core to be drawn up; this closes the stator circuit of the motor and also the fine wire circuit at E. Current in the stator at once in-

duces currents in the rotor and these draw up the cores of 5 opening the circuit underneath until the rotor has attained some speed. As the rotor attains speed the currents in it grow weaker and the cores of 5 drop back closing the circuit underneath again.

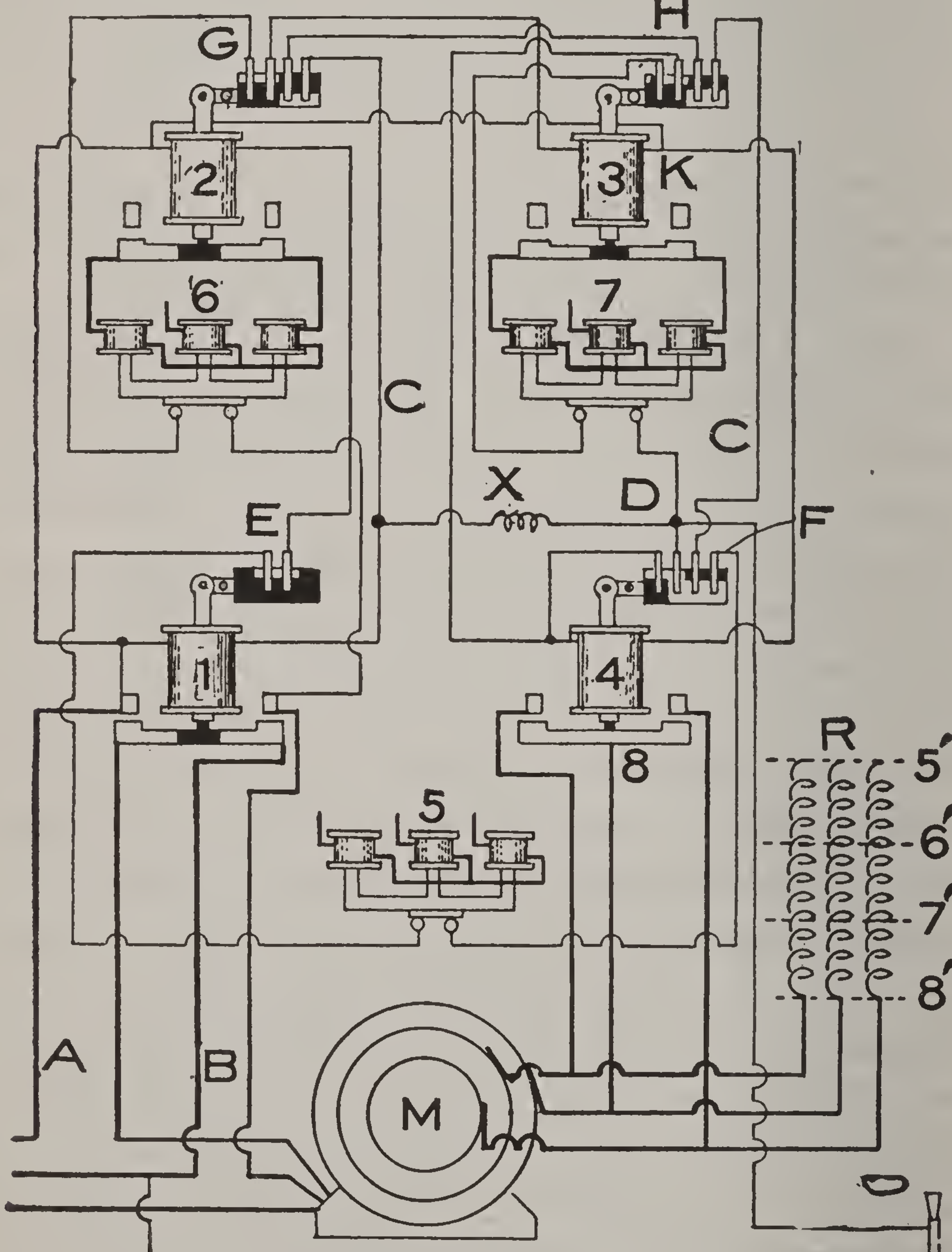


FIGURE 154a.

As the circuit is now closed at E and underneath 5, current passes from phase A through solenoid 2 to E point D and thence to pilot switch and phase B. This causes 2 to draw up its core and the rotor resistance becomes short circuited at 6′. The small solenoids act as those at 5 momentarily opening the circuit and then closing it again. Drawing up the core of 2 closes the circuit at the left of G and opens that at the right. Current now passes from the left of 2 to the right of solenoid 3 thence to G and phase wire B at 1. Line C is now open and current passes from 1 through X to the pilot switch. This reduces the current leaving only as much as is necessary to maintain the core of 1 against gravity.

Solenoid 3 now acts closing the circuit at the left of H and under 7. This sends current from point K through solenoid 4 to the left half of H point D and pilot switch.

When solenoid 4 acts it short circuits all of the resistance of the rotor and develops the full power of the motor. In its action it also closes the circuit of F at the left and opens it at the right. Closing the circuit F at the left establishes a circuit for 4 to point D, and at the same time opening of F at the right breaks the circuit of 2, and this core descending breaks the circuit of 3 at the left of G. Two circuits now remain closed, one through solenoid 1 resistance X to point D, the other around 2 and 3 to 4 left side of F and point D thence to pilot switch and phase B.

By tracing out the various circuits it can be seen that the arrangement is such that solenoid 2 cannot act unless 3 and 4 are in the off position and that 3 cannot work unless 2 has acted and 4 must in turn wait on 3. The motor can therefore not be started unless all of the resistance is inserted in the rotor circuit.

In Figure 154t a motor testing board suitable for use with two or three phase currents is shown. The

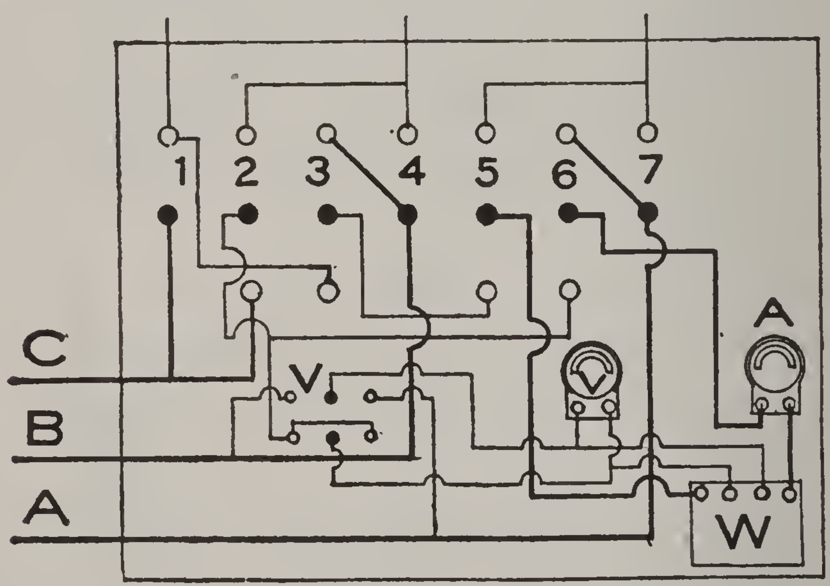


FIGURE 154t.

current in each phase may be measured and thus the degree of unbalancing of the circuit on individual motors determined. In practice it is found that very many motors are considerably out of balance electrically.

The ammeter A is shown in connection with the wattmeter so that the power factor of the motor may be determined. The power factor is found by dividing

the indicated watts of the wattmeter by the product of the volts and amperes existing at the same time. The power factor is always less than unity.

The switches indicated are all single pole with exception of the voltmeter switch V. If 1, 4 and 7 are thrown upward the motor feeds direct from the line A B C.

To test A for current throw 5 and 6 up and open 7; to get voltage A C throw V to right and 2 down.

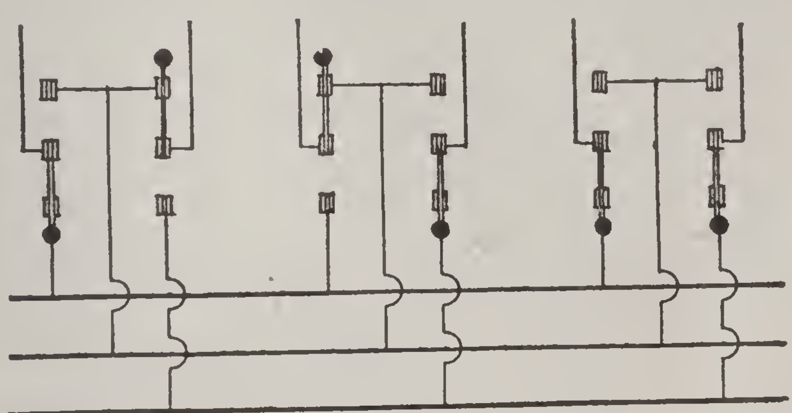


FIGURE 154u.

To test B for current throw 3 up, 5 and 6 down, and 2 up, and open 4; to get voltage A B throw V to right.

To test C for current throw 2, 6, 5, and 3 down and open 1. to get voltage C B throw V to the left.

There is often considerable trouble on three phase circuits from an unbalanced load. For the best service the current in all three wires should be the same. A simple method by which any one of the branch circuits may be transferred to any one of the phases is illustrated in Figure 154u. As shown each branch circuit is connected to a different phase.

In Figure 154v the connections of the Westinghouse frequency meter are shown. The frequency meter is simply a voltmeter with two opposing coils acting upon the pointer. Placed in the circuit this way there would be no indications.

In order to make it indicate different frequencies an inductive resistance is placed in circuit with one of the

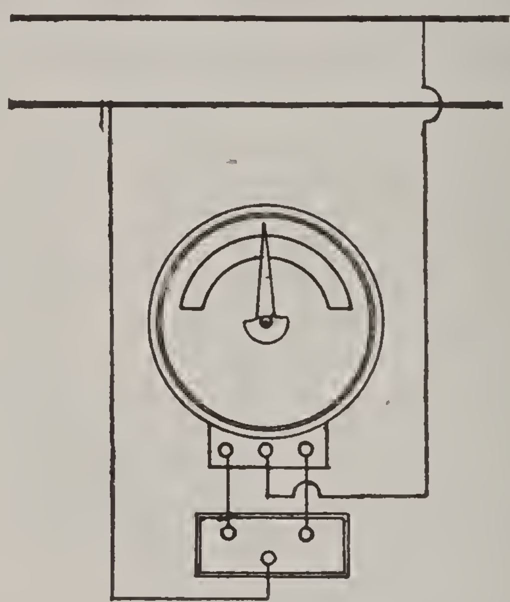


FIGURE 154v.

coils and a non inductive resistance with the other. These resistances are placed in a separate case and mounted near the instrument to which they must be connected as shown. The frequency meter in any given case is of course simply a speed indicator since the frequency of the dynamos depends upon the speed with which they revolve.

The connections of the Westinghouse portable powerfactor meter are shown for three phase circuit in Figure 154w and for two phase in Figure 154x.

The two phase meter has two and the three phase meter three coils which form the fields. In addition there is another coil the currents of which are in phase with the voltage. A rotating field is produced by the main coils, and this field controls the position of the pointer attached to the movable coil. The connections

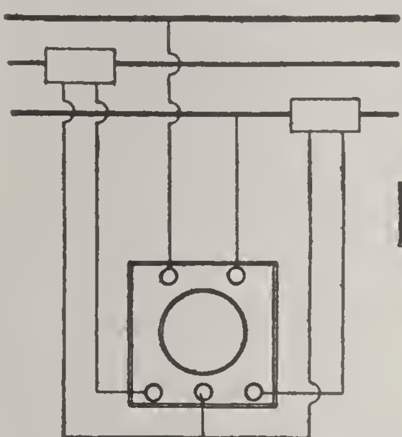
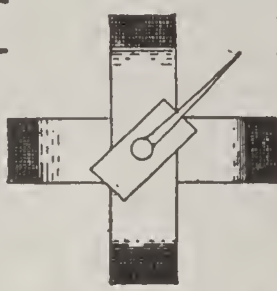


FIGURE 154w.



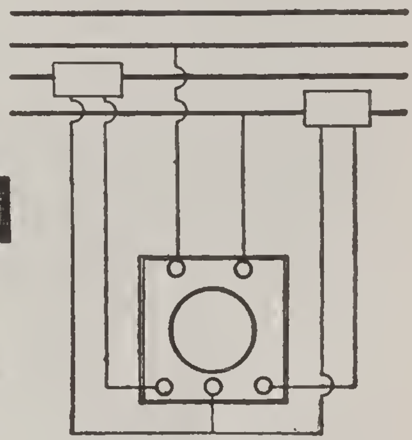


FIGURE 154x.

to the movable coil are shown at the top and the arrangement for two phase is shown in center.

The following instructions are quoted from publications of the Westinghouse Company: "When the top binding posts are disconnected and there is current of at least one half full load in the series transformers, the pointer should rotate in the 'lead' direction. If it rotates in the 'lag' direction reverse the leads running to the lower left hand binding posts. On a two phase circuit the reversal should be made at the series transformer shown at the left of the diagram. On a three phase circuit the leads should be reversed at the meter by connecting the common wire from the

two series transformers to the left hand binding post, and the single wire from the series transformer on the left to the middle post. Then connect the shunt circuit to the upper binding posts as shown. This shunt connection should be made to the phase which is connected through the series transformer to the right hand side of the meter. Should it be necessary to reverse the series connection of the meter on three phase circuits from that shown on the diagram in order to obtain proper rotation, the shunt wire which is shown connected to the wire of the circuit having no series transformer should be changed to the wire which is connected through the series transformer to the left hand side of the meter. The upper half of the scale indicates for power delivered from alternating-current lines to the motor or rotary, and the lower half, power returned to the lines. Should the pointer indicate the reverse of that given above, the connections at the upper binding posts should be reversed.

"Move the scale by means of the projecting studs at the sides of the dial, until the 'frequency index' at the lower right hand portion of the scale points to the line marked with the number of alternations of the circuit on which the instrument is being used. The instrument will now indicate the power factor of the circuit."

Figure 154y shows the ordinary connections of Westinghouse synchroscopes for voltages between 1 and 200.

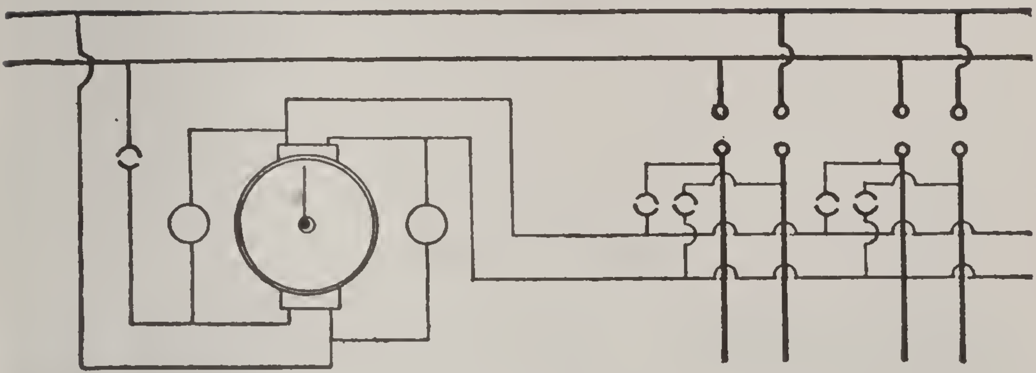


FIGURE 154y.

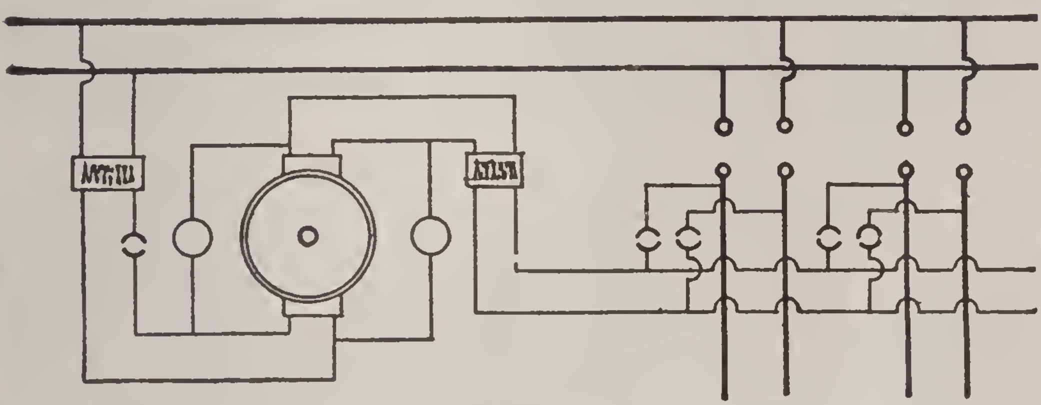


FIGURE 154z.

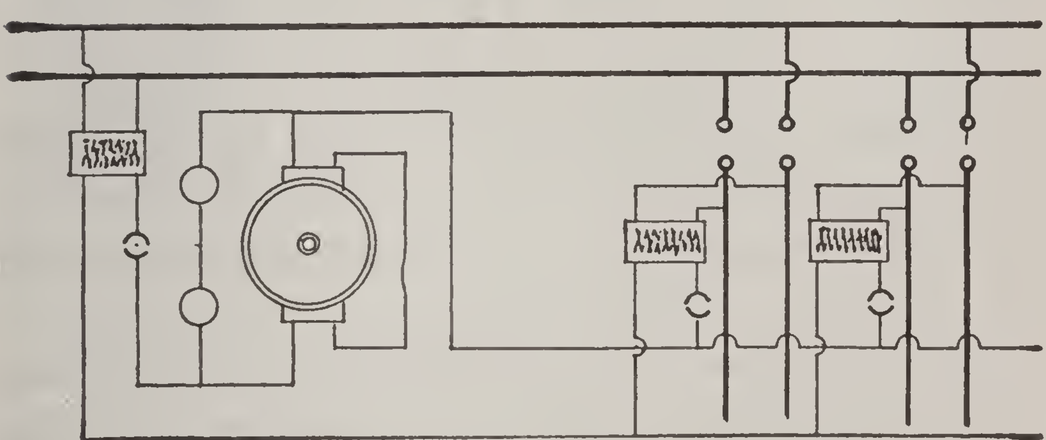


FIGURE 154′.

The connections for voltages from 200 to 500 are given in Figure 154z and those for voltages in excess of 500 in Figure 154′.

TRANSFORMERS.

Figure 155 shows the circuits in a single-phase transformer.

Figure 156 shows the circuits in a single-phase transformer with a three-wire secondary. This transformer has the advantages derived from the use

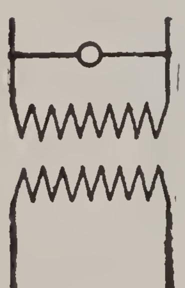


FIGURE 155.

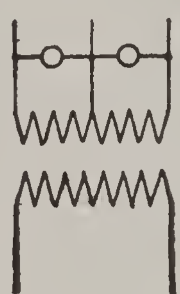


FIGURE 156.

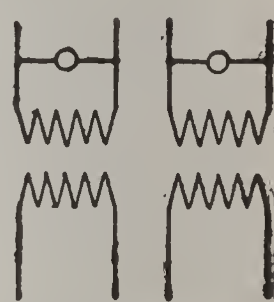


FIGURE 157.

of three-wire distributing circuits, and is used where a large installation is to be connected, or where one large transformer feeds a set of secondary mains supplying a number of residences.

Figure 157 shows the connections of a two-phase transformer with two separate secondaries; and Figure 158 the two-phase transformer with a common return wire for the secondaries.

Figure 159 shows a three-phase delta connection, and Figure 160 a three-phase star connection.

Figures 161 to 167 show the connections used on the Packard Mark VI. transformers. The primary windings of these transformers are made in two sec-

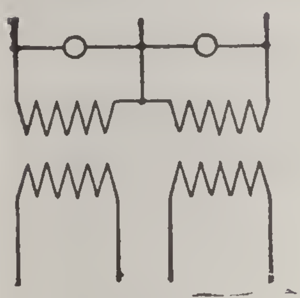


FIGURE 158.

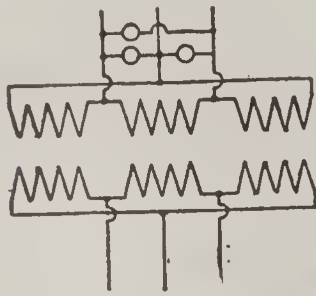


FIGURE 159.

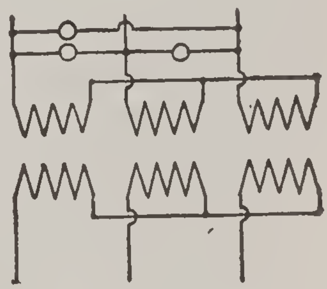


FIGURE 160.

tions, with leads brought out so that they may be connected either in series or parallel. When used on 2000 volt systems the two sections are connected in

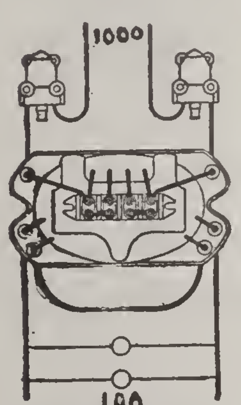


FIGURE 161.

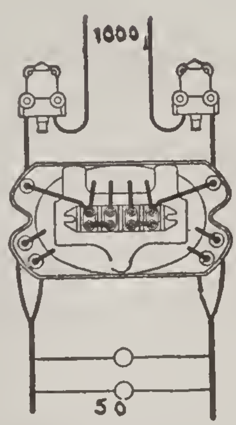


FIGURE 162.

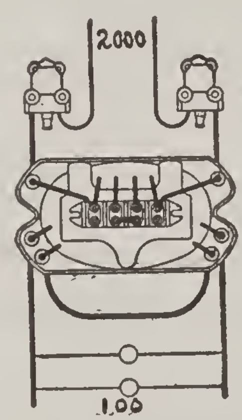


FIGURE 163.

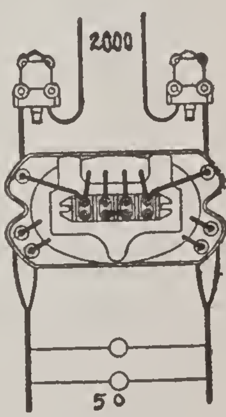


FIGURE 164.

series, and when used on 1000 volt systems the two sections are connected in parallel. These connections are shown in the diagrams, where, in Figures 161 to

164, terminal blocks are used, and in Figures 165 and 168 the primaries are connected in the same way as the secondaries. The secondaries of these transformers are also wound in two sections, the same as the primaries, so that either 50 or 100 volts or 100 or 200 volts may be obtained, according to the type of the transformer used. In Figures 161, 162, 165, 166, the primary windings are connected in multiple; while in Figures 163, 164, 167, 168, the primary

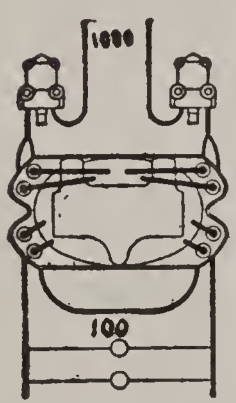


FIGURE 165.

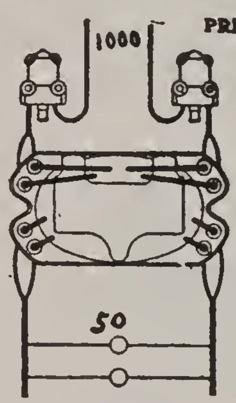


FIGURE 166.

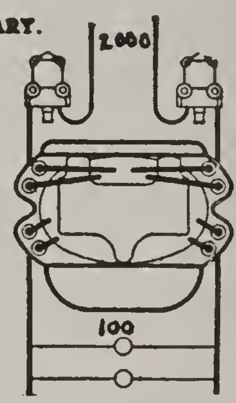


FIGURE 167.

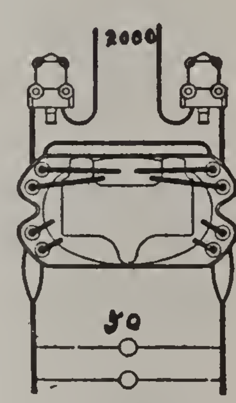


FIGURE 168.

windings are connected in series. The two secondary windings are connected in series in Figures 161, 163, 165, 167, and in multiple in Figures, 162, 164, 166, 168.

When a current of electricity is sent through a wire lines of force are sent out completely encircling the wire. As long as the current in the wire remains constant these lines of force remain constant, but, if the current increases the lines of force increase, or

if the current decreases the lines of force decrease. If the wire is wound into a coil as the current in the wire increases the lines of force sent out from each wire of the coil will have to cut through all the other wires on the coil and in so doing they induce a counter-electromotive force which is in opposition to the impressed electromotive force. It can readily be seen that this counter-electromotive force tends to hold back the rise in current or make it lag behind the E. M. F. In the same way, when the current in

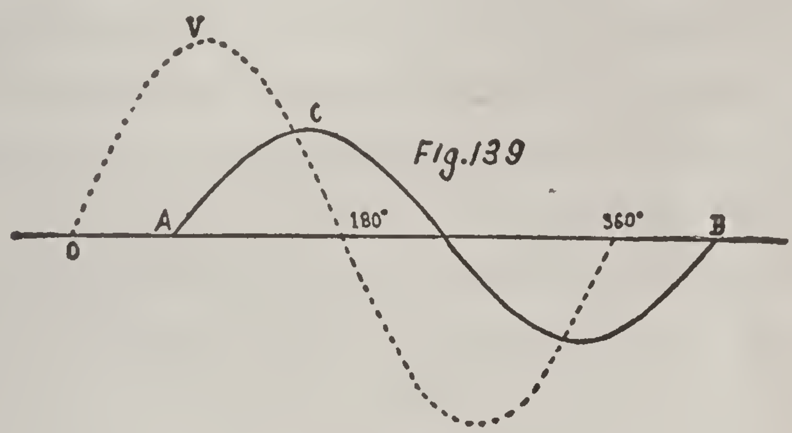


FIGURE 169.

the coil decreases in strength the lines of force closing in on the wire add their E. M. F. to that of the impressed E. M. F. and tend to prolong the current, again causing the change in the current to follow or lag behind the E. M. F. This is shown by the curve (Figure 169), where C represents the current and V the E. M. F. This action is called self-induction. Self-induction in a circuit acts in the same way as resistance: it tends to cut down the cur-

rent. For an illustration: suppose the resistance of the wire in the coil just referred to was 5 ohms. A direct current of 110 volts would cause a current of 110/5=22 amperes to flow through the coil. But if we were to send an alternating current at 110 volts through the coil we would find that the resulting current would be much less than 22 amperes and if we inserted an iron core in the coil the current would be still farther reduced, because the resistance of iron to the lines of force is much less than with air so that the lines of force would be increased in number. The frequency of the current, or the rapidity of the alternations also effects the amount of current produced, the current being smaller the greater the number of alternations.

A condenser connected in a circuit acts in a way similar to an inductance except that the condenser causes the current to lead the E. M. F. in phase. When an alternating current flows along a circuit across which a condenser is connected, as the E. M. F. in the line rises the condenser is gradually charged, the charge increasing in value as long as the current is rising. As the E. M. F. in the line begins to fall the E. M. F. across the condenser terminals lowers and the condenser begins to discharge into the line continuing to discharge until the impressed E. M. F. has passed through 0 and reached a maximum negative value. At this point the current again begins to flow into the condenser. It will be seen that

while the E. M. F. in the line is passing from a maximum positive value to a maximum negative value that the condenser current is negative or flowing out of the condenser and while the E. M. F. in the line passes from a maximum negative value to a maximum positive value the current in the condenser is positive. The condenser current reaches a maximum 90 degrees in advance of the E. M. F. and for this reason is known as a leading current.

In a circuit containing inductance or capacity, where the current is out of phase with the E. M. F. the current may be resolved into two currents, one of which is in phase with the E. M. F. and the other 90 degrees out of phase with the E. M. F. This latter current is known as a wattless current and is greater, the greater the inductance or capacity in the circuit.

If in a circuit containing inductance or capacity where the current is out of phase with the E. M. F., we would measure the power in watts, using a voltmeter and ammeter, W = C. E., we would get an apparent amount of power which would be greatly in excess of that actually consumed. The number of watts actually consumed could be measured by a wattmeter. The ratio of the number of watts actually consumed to the apparent watts is known as the power factor, or Power factor=Actual watts divided by apparent watts. As an example: suppose the voltmeter and ammeter showed 115 volts and 10 amperes which would be equal to 1150 watts and the watt-

meter shows 920 watts. Then 920/1150=80/100 or .80 which is the power factor. The actual current doing work would amount to 8 amperes but as shown by the ammeter 10 amperes is flowing and the wire and fuses on such a circuit would have to be of sufficient size to carry 10 amperes.

CHAPTER XVI.

ARMATURES.

Figure 170 is a diagram of a Gramme ring armature. This style is often used with series arc lighting machines. It is well suited for high voltages but not for heavy currents.

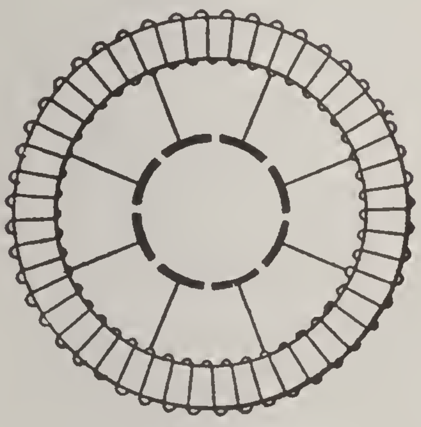


FIGURE 170.

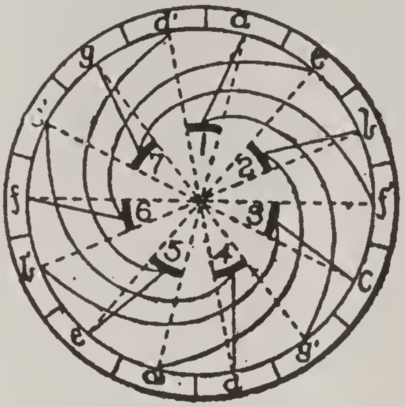


FIGURE 171.

The winding shown in Figure 171 is that of an ordinary cylinder or drum armature. The wire wound on this armature as well as that of the preceding always forms one continuous coil or loop. This can be seen by tracing the wire beginning at commutator bar 1, thence to section *a*, around back of core to *a′* and then to commutator bar 2. From this bar to *b*, then to *b′* and commutator bar 3, etc. This is one of the simplest windings used, but many makers are

using modifications of it; the principle of all, however, being the same.

Figure 172 shows a diagram of Thomson-Houston ring armature used for series arc lighting. This armature consists of three sections which terminate at three commutator segments from which current is taken off. The other terminals of all three sections terminate in a copper ring which joins all of them together.

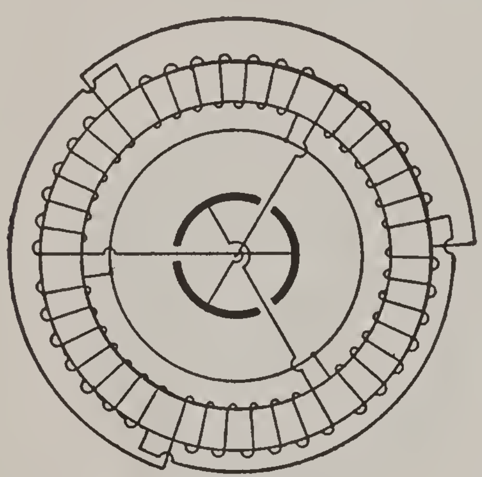


FIGURE 172.

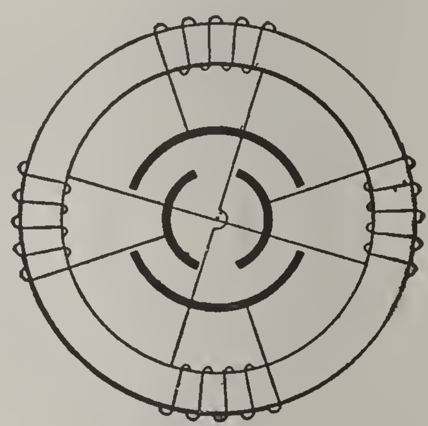


FIGURE 173.

A diagram of the Brush armature, also for series arc lighting, is shown in Figure 173. The figure shows only two sets of coils, although in actual practice many more are used. In this style of armature some of the coils are always on open circuit and it will be seen that there is no connection whatever between the different coils except through the commutator segments and the brushes resting upon them.

Figure 174 illustrates the winding of an armature such as is used in single-phase alternating current

machines. The number of coils on the armature must always be equal to the number of poles in the fields. With dynamos of this kind quite often the fields are made to revolve and the current to the outside lines flows from the stationary coils on the frame.

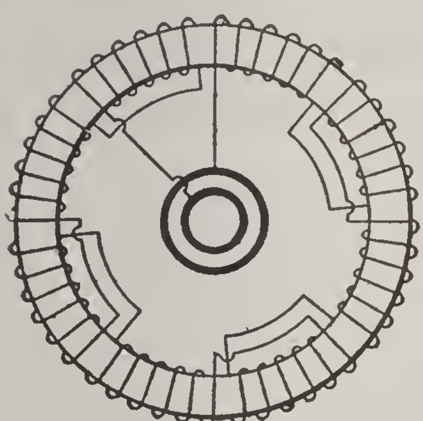


FIGURE 174.

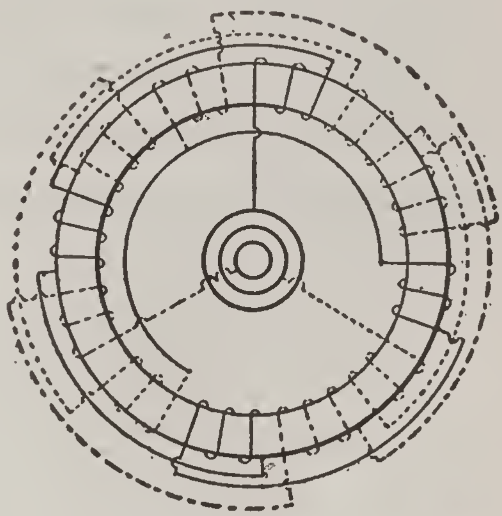


FIGURE 175.

In Figure 175 a diagram of a three-phase, four-pole, star connected armature is shown. The winding for each separate phase is similar to that of the single-phase armature. One end of each coil terminates in a collector ring; the other ends of all the coils meeting in one common connection. It will be noticed that there are three coils (one for each phase) for every pole piece, making twelve coils in all.

CHAPTER XVII.

SWITCHBOARDS—GROUND DETECTORS.

Figure 176 shows the wiring and connections of the Western Electric Co.'s series arc switchboard. At the top of the board are mounted six ammeters, one being connected in the circuit of each machine. On

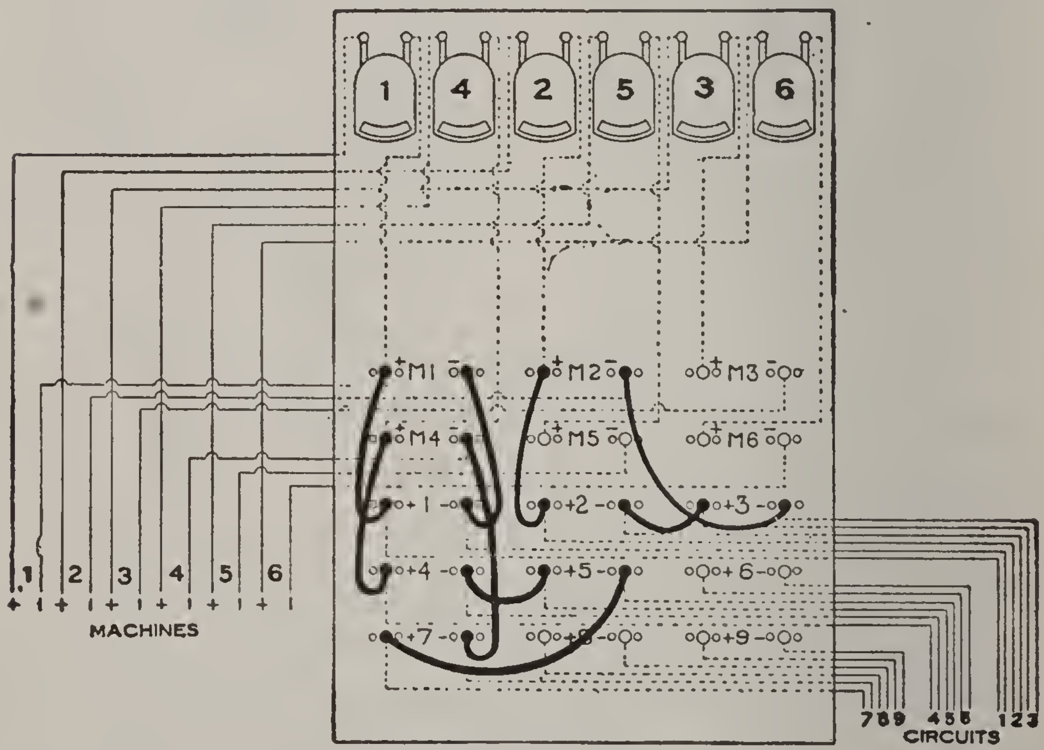


FIGURE 176.

the lower part of the board are a number of holes, under which, on the back of the board, are mounted spring jacks to which the circuit and machine terminals are connected. For making connections be-

tween dynamos and circuits, flexible cables terminating at each end in a plug, are used; these are commonly called "jumpers." The board shown has a capacity of six machines and nine circuits, and with the connections as shown machine 1 is furnishing current to circuit 1, machine 2 is furnishing current to circuits 2 and 3, and machine 4 is furnishing current to circuits 4, 5 and 7. In connecting together arc dynamos and circuits the positive of the machine (or that terminal from which the current is flowing) is connected to the positive of the circuit (the terminal into which the current is flowing). Likewise the negative of the machine is connected to the negative of the circuit. Where more than one circuit is to be operated from one dynamo, the — of the first circuit is connected to the + of the second. At each side of the name plate (at 3, for instance) there are three holes. The large hole is used for the permanent connection, while the smaller holes are used for transferring circuits, without shutting down the dynamo. Smaller cables and plugs are used for transferring. If it is desired to cut off circuit 5 from machine 4, a plug is inserted in one of the small holes at the right of 4, the other plug being inserted in one of the holes at the left of 7. Circuit 5 would now be short circuited, and the plug in the + of 5 can now be transferred to the permanent connection in the + of 7, and the cords running to 5 removed. If it is desired to cut in a circuit, say circuit 6 onto machine 2, in-

sert a cord between the — of circuit 2 and the + of 6 and another between the — of 6 and the + of 3. Now pull the plug on the cord connecting — of 2 and the + of 3 and insert the permanent connections. In cutting in circuits, if they contain a great number of lights, a long arc may be drawn when the plug between 2 and 3 is pulled, and it is sometimes advisable to shut down the machine when making a change of this kind.

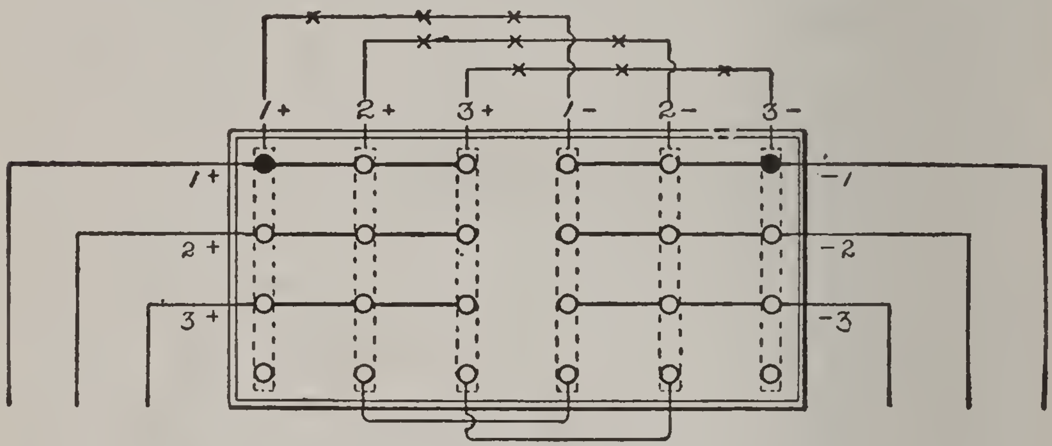


FIGURE 177.

Figure 177 is a diagram of the Thomson-Houston arc switchboard. The generators connect to horizontal brass strips fastened to the back of the board, as indicated by the heavy black lines. The circuits connect to similar strips fastened vertically to back of board but separated from the horizontal strips. These vertical strips extend below the horizontal strips and terminate in a number of plug holes shown at the bottom. Long plugs are provided suitably constructed to make connection between any of the

horizontal generator strips and any of the vertical circuit strips. The lines at the bottom indicate plugs connected by short cables and by tracing out the circuits it will be seen that all three are in series with generator 1. The positive sides of all dynamos are usually run to one side of the board and the positive sides of all circuits to the same side, so that only through gross carelessness could wrong plugging, as to polarity, exist.

A, B, C, D and E, Figure 178, illustrate the successive steps necessary to change circuits 1 and 2 from dynamo 1 and 2 and connect them in series on dynamo 2. The solid black circles represent plugs.

The first step is shown in B where the positive poles of both dynamos are placed in parallel by inserting the two additional plugs.

The second step is to withdraw the two first plugs shown in A. This places the two dynamos in series, D1 connecting direct to circuit 2, as shown at C.

The voltage of dynamo D1 may now be reduced and two plugs with cable connections inserted, as shown at D. This short-circuits dynamo D1 and leaves D2 carrying the load of both circuits.

The plugs connecting D1 to the circuit may now be withdrawn, leaving the connections as at E, where dynamo D2 supplies both circuits.

In F two circuits are shown as running in series on dynamo D1 and the insertion of plug H serves to

short-circuit and extinguish circuit 2. The plugs **I**, **J** and **K** may now be withdrawn.

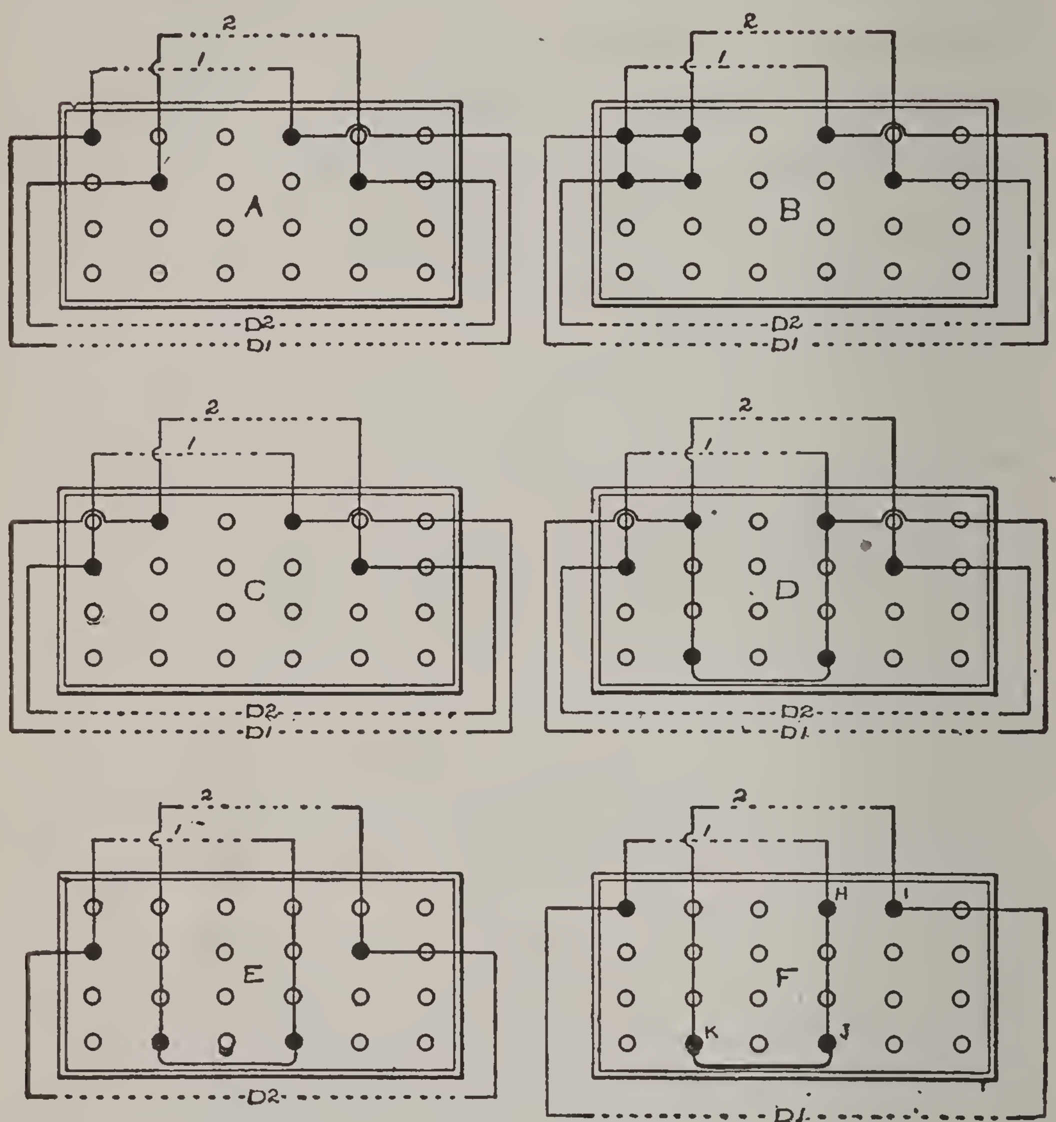


FIGURE 178.

In Figure 179 the switchboard connections and all necessary instruments for operating a single (shunt or compound) dynamo are shown. Such a board could be used on a small isolated plant. At the left a front view with the instruments is shown, while at

the right is a rear view showing the connections. Referring to the view at the left, V is a voltmeter and A an ammeter with scales suitable to the voltage and current used. PL is a pilot lamp. The ground detector switch GD is used to measure the insulation resistance to ground of each side of the system. In

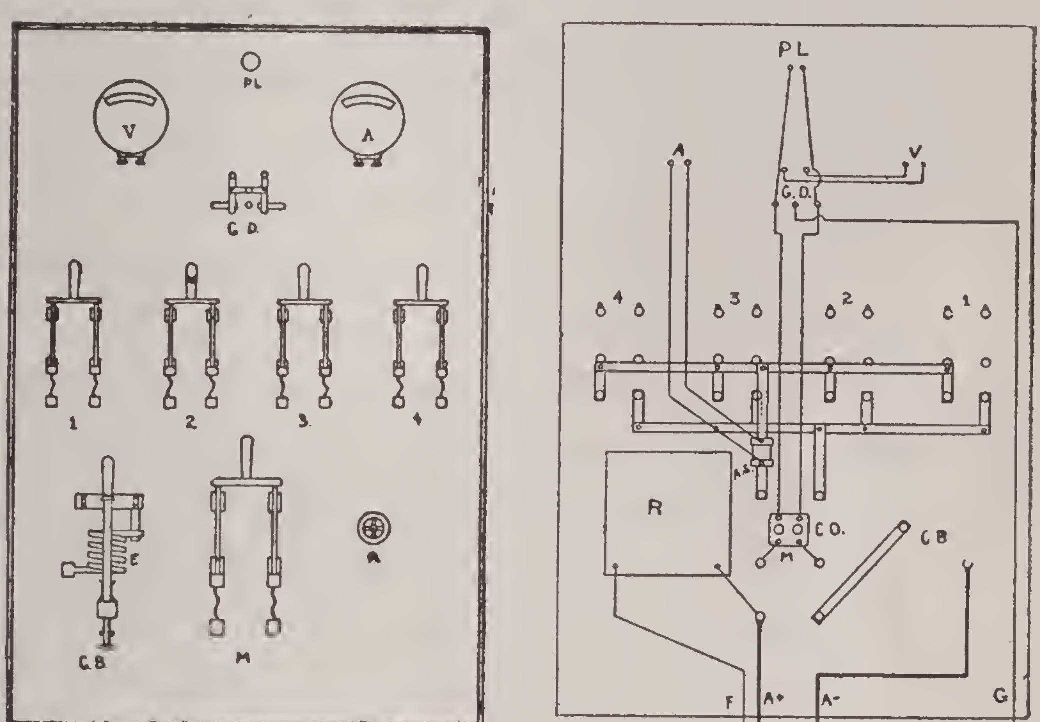


FIGURE 179.

the position shown the voltmeter is connected directly across the bus bars. If the switch is moved to the right, the + bus bar is connected through the voltmeter to ground, and, by means of the reading obtained, using the formula given under the head of testing, the insulation resistance can be determined. Moved to the left, the insulation resistance of the other side of the system can be obtained. One of the

dynamo leads is carried to one terminal of the main switch M, while the other lead is carried through the circuit breaker CB to the other terminal of the switch. The circuit breaker is generally set to operate at a lower rise in current than the fuses on switch M, so that these fuses only blow in case the circuit breaker fails to operate. The circuit breaker is not absolutely necessary, but is generally installed in well designed plants. The small hand wheel R is connected to the rheostat mounted on the rear of the board. The switches 1, 2, 3 and 4 operate the feeder lines. On the rear of the board the three wires F, A + and A —, go to the dynamo, while the line marked G is connected to some good ground, such as a water pipe. The rheostat R is connected in series with the shunt field, and is used to regulate the voltage. AS is a shunt connected in series with one of the bus bars, the terminals of the shunt being connected to the ammeter. This shunt is generally furnished with the ammeter. In case an ammeter which carries the entire current is used, leads must be carried to the ammeter so that it will be connected in series with one of the mains. The feeder lines are connected to the upper terminals of switches 1, 2, 3, and 4. The ground detector, pilot lamps and voltmeter are connected to the bus bars through the cutout CO, standard No. 14 rubber covered wire being used on these circuits.

GROUND DETECTORS.

In Figure 180 a ground detector switch suitable for mounting on a switchboard is shown. Two arms A, A′, pivoted at their upper ends, are connected together with an insulating bar B. These arms make contact at their lower ends with two brass strips and a contact button which are connected to the bus bars and ground respectively. When the arms are moved to the left the + bus bar is connected to ground

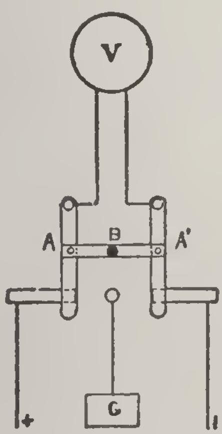


FIGURE 180.

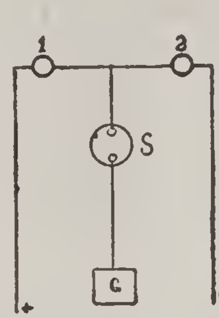


FIGURE 181.

through the voltmeter V. By means of the reading obtained the insulation resistance to ground of the — side of the line can be calculated by using the formula given further on. By moving the arm to the right the insulation resistance of the + side of the line can be obtained.

Figure 181 shows a lamp ground detector. On a 110-volt system two ordinary 110-volt lamps are connected in series, while the line connecting the lamps

is connected to ground through a snap switch S. When current is on, the two lamps will burn with equal brilliancy at a low candle-power. When the switch S is closed, if the two lines are clear the brilliancy of the lamps will not be affected; but if there is a ground on the + side of the line lamp 2 will burn brighter, the brightness depending on the resistance of the ground. If there is a dead ground the lamp will burn at full candle-power, lamp 1 not burning at all. If the ground is on the — side of the line lamp 1 will burn brighter.

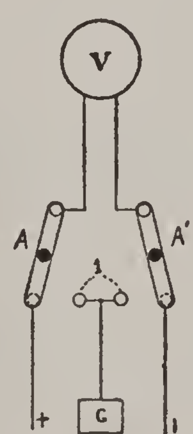


FIGURE 182.

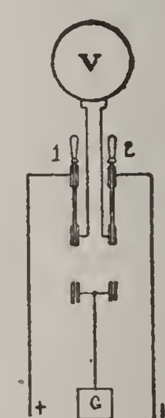


FIGURE 183.

Figure 182 shows another method of using a voltmeter as a ground detector. The arms A A′ are hinged at the upper ends and swing separately. Arm A moved to post 1 gives the reading on the + side, and arm A′ moved to post 1 gives the reading on the — side of the line.

Figure 183 shows another method, using two single-pole double-throw knife switches. Throwing

switch 1 to lower position connects the — bus bar to ground, and gives the insulation resistance of the + side of the line.

Another form in which two double-point push buttons are used is shown in Figure 184. In normal position contact is made to the upper points so that the voltmeter is always connected across the bus bars. Pushing button 1, the insulation resistance of the + side of the line can be obtained, and pushing button 2 the — side.

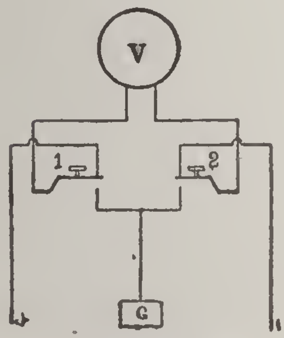


FIGURE 184.

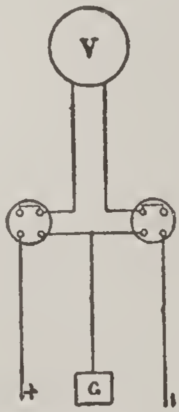


FIGURE 185.

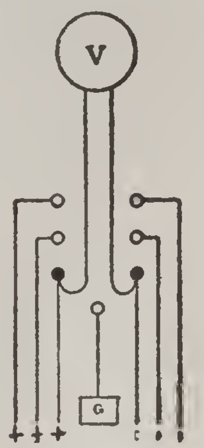


FIGURE 186.

Three-way snap switches are used for the same purpose in Figure 185.

When several machines are in operation the method shown in Figure 186 can be used. With this arrangement the voltage can be taken on any one of several lines or machines, and also the insulation resistance to ground. The voltmeter connection is made by means of flexible cords terminating in plugs, which fit in the jacks, which in turn are connected to the machine leads or to the various circuits.

The switch shown in Figure 187 is designed for use where two dynamos are run in parallel. An arm A pivoted at the center is equipped with brass strips, which, by moving arm A, make contact between the center curved piece and the contact points 1, 2, 3 and 4. With the arm moved down the voltmeter is connected to machine No. 1, and with the arm moved up the voltmeter is connected to machine No. 2. By a slight movement of the arm the voltage of either

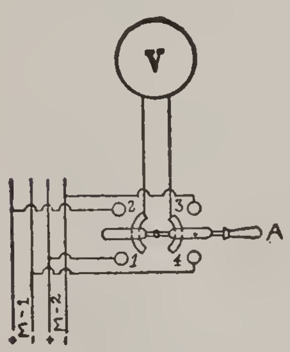


FIGURE 187.

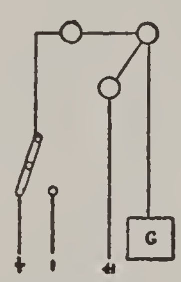


FIGURE 188.

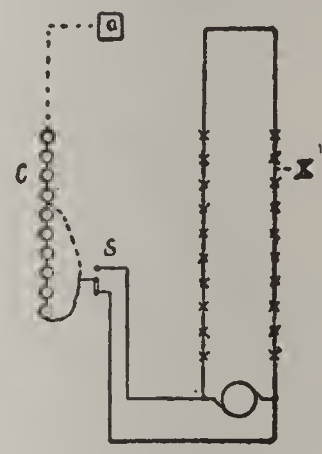


FIGURE 189.

machine can be taken. This is useful where a dynamo is being brought up to speed to connect on to the bus bars.

Figure 188 shows a lamp ground detector for use on a three-wire system where the neutral is not grounded. In nearly all three-wire systems the neutral is either permanently grounded or becomes grounded so that ground detectors are not used, a ground on either of the outsides blowing a fuse.

Figure 189 shows a method of locating grounds on

a series arc line, where lamps are burning. A number of incandescent lamps are connected in series, the last lamp being connected to ground. Two wires are carried to the double-throw switch S, one wire being connected to each side of the circuit. From the middle of the double-throw switch a flexible connection is carried to the first lamp, and the brightness of the lamps noted. If the lamps do not burn up to full candle power, connection is made at some lamp nearer the ground, and this continued until the lamps burn at full brightness. When this point has been reached the number of lamps is counted, and if 100-volt incandescent lamps are used it will be seen that there are just twice as many arc lamps burning between that side of the machine and the ground as there are incandescents burning, for an arc lamp takes approximately 50 volts. In the diagram suppose there is a ground on the arc circuit at X; then, with the connection to the incandescent lamps as shown in the dotted lines, the lamps will burn at full brightness. Care should be taken in handling apparatus of this kind on account of the high voltages on arc circuits on which there are a number of lamps.

Figure 189a shows diagram of ground detector connections on a two phase circuit. A lamp is connected in parallel with the inductance and by connecting the lamp to different points as 1 or 4 for instance, an idea of the resistance to ground can be formed. If the lamp will burn brightly at point 4 it indicates that the

insulation resistance of the line to ground is much lower than it would be if it would have to be connected at point 1 to burn brightly.

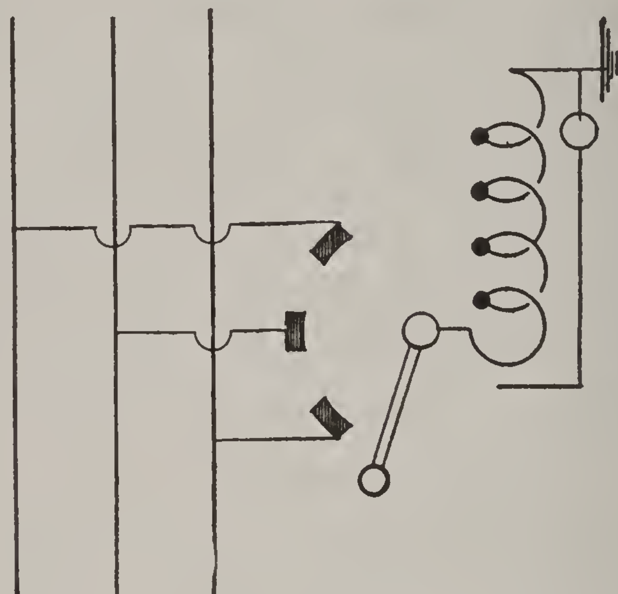


FIGURE 189b.

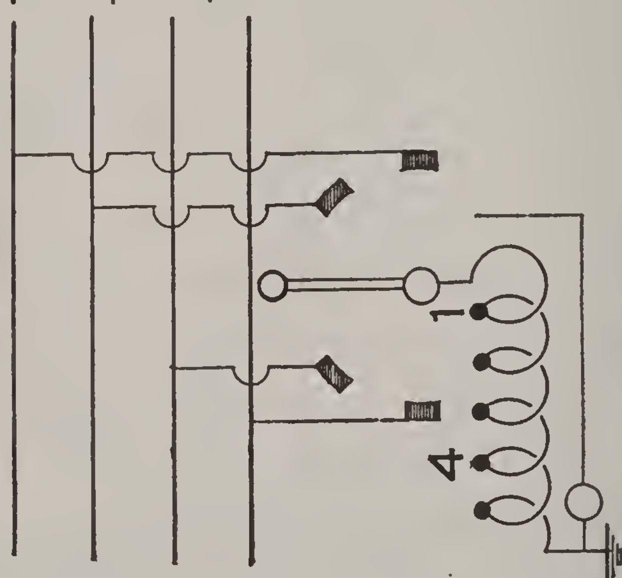


FIGURE 189a.

A similar plan for three phase circuits is followed in Figure 189b.

As with other ground detectors, if the ground switch is connected to the leg that is grounded the lamp will not burn at all.

Figure 189c shows ground detector arranged for high potential service. Two voltmeters are connected through two transformers as shown. If the line is clear the two voltmeters show low readings which are equal for both instruments. With a ground coming on at A and the switch closed to guard the meter at the

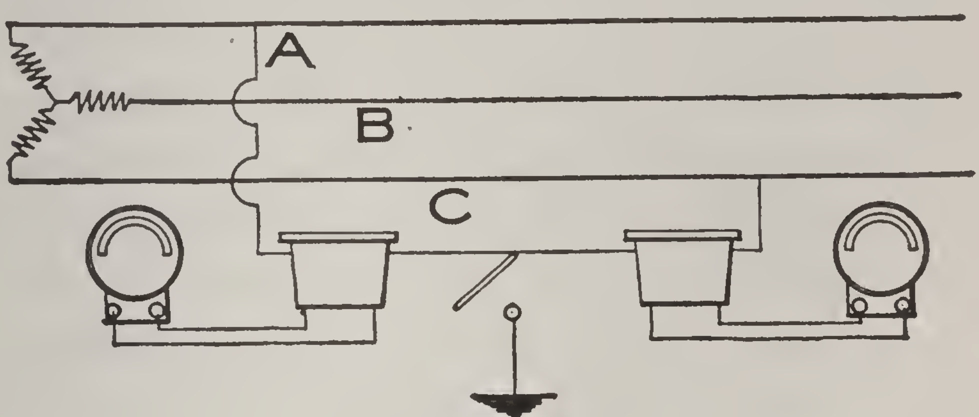


FIGURE 189c.

left will indicate lower and that on the right higher. With a ground coming on at C the indications will be the reverse, while with a ground at B both voltmeters will read higher.

CHAPTER XVIII.

STORAGE BATTERY CONNECTIONS.

Figure 190 shows a diagram of connections of a storage battery and booster suitable for an ordinary electric light installation, where it is desired to use the battery at time of heavy load to assist the generator, and to use the battery alone at time of light load. The booster B, which is driven by the motor M, the two forming a motor generator set, is connected in series with the battery circuit, and serves to raise the voltage to that necessary to charge the batteries. R is a rheostat in the field of the booster by which the E. M. F. can be regulated.

To charge, the double-throw switch S is thrown downward and the single-pole switch is closed, the end-cell switch E being placed on point 5 so that all the cells are in circuit. The motor is now started, and when it is up to speed the arm of the motor rheostat closes the charging circuit at C. To discharge, throw the end-cell switch E to point 1 and throw double-throw switch S upward. The battery is then in parallel with the generator. To run with the batteries alone open switch MS.

As the E. M. F. of the battery falls, more end-cells are switched in by moving switch E to points

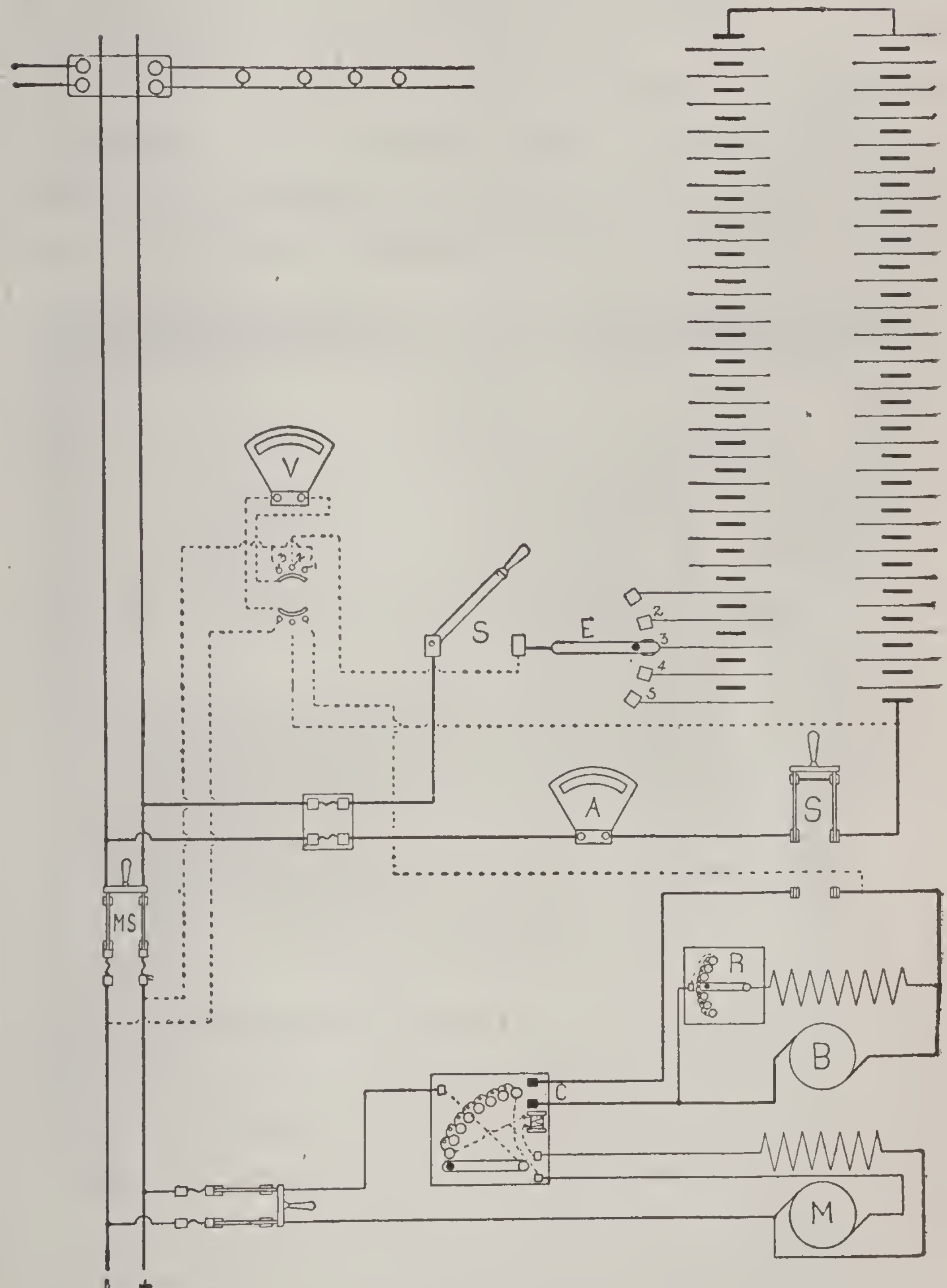


FIGURE 190.

2, 3, 4 or 5. A separate voltmeter is generally installed so that the readings of the voltage may be taken from the end-cells separately, to prevent overcharging or exhausting them.

In power work, where variations in voltage are greater and not of so much importance, storage batteries are often connected directly across the mains

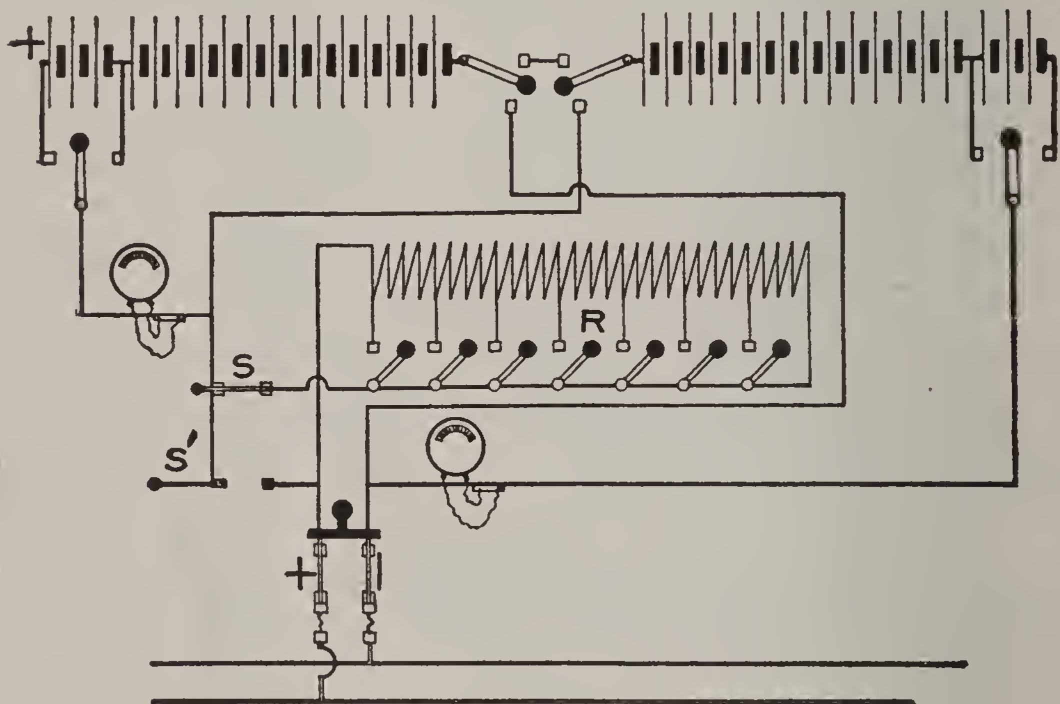


FIGURE 190a.

without a booster. In such cases the battery will take current from the mains when the load is light and the voltage correspondingly high, and give current into the line when the voltage becomes low due to heavy loads.

Figure 190a shows connections of a storage battery to be charged without the use of a booster. For charging, the battery is connected with the two halves

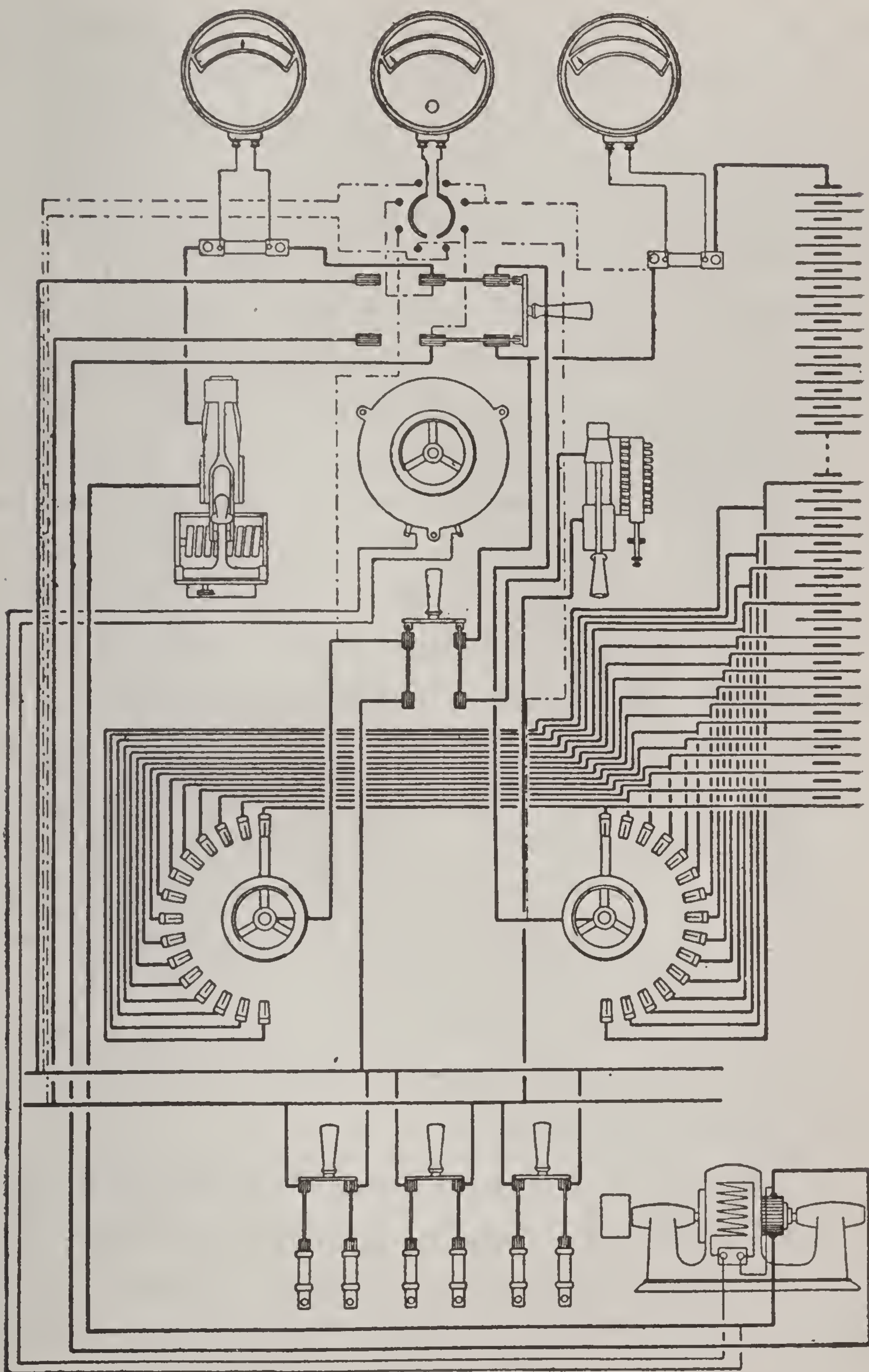


FIGURE 190b.

in parallel. As shown the battery is ready for charge if the single pole switches at the center are closed downward, and those at the right and left placed to their proper positions with the end cells in circuit. As the E. M. F. of the battery builds up sections of the resistance R, beginning at the right, are cut out. An ammeter is provided in each leg so that the rate of charge of each half of the battery may be observed. When fully charged the main switch is opened, switch S is then also opened, S′ is closed and the single pole switches at the center of the battery are closed on the upper points. This places the two halves in series and fit for connection to the line. The end cells should be adjusted so that the voltage of the battery is about equal to that of the line before it is thrown in.

Figure 190b shows diagram of storage battery as arranged by the Gould Co., to be charged from a high voltage (150 volt) dynamo. A separate set of end cell switches is provided for charge and discharge so that both may be taking place at the same time. There are two circuit breakers, the one at the right is provided with a reverse current trip to protect the dynamo in case its voltage should fall so that the battery could send current through it.

In Figure 190c a large automobile charging station is shown. As a battery is connected for charge the corresponding switch S is thrown upward. This allows current to pass through the ammeter A, and the rheostat is now set so that the current flow is at

the proper rate. When this is done the switch is thrown downward, this leaves the ammeter free for use with the next charge. By entirely opening the switch and inserting plug at P in the corresponding circuit the voltage of any battery can be taken.

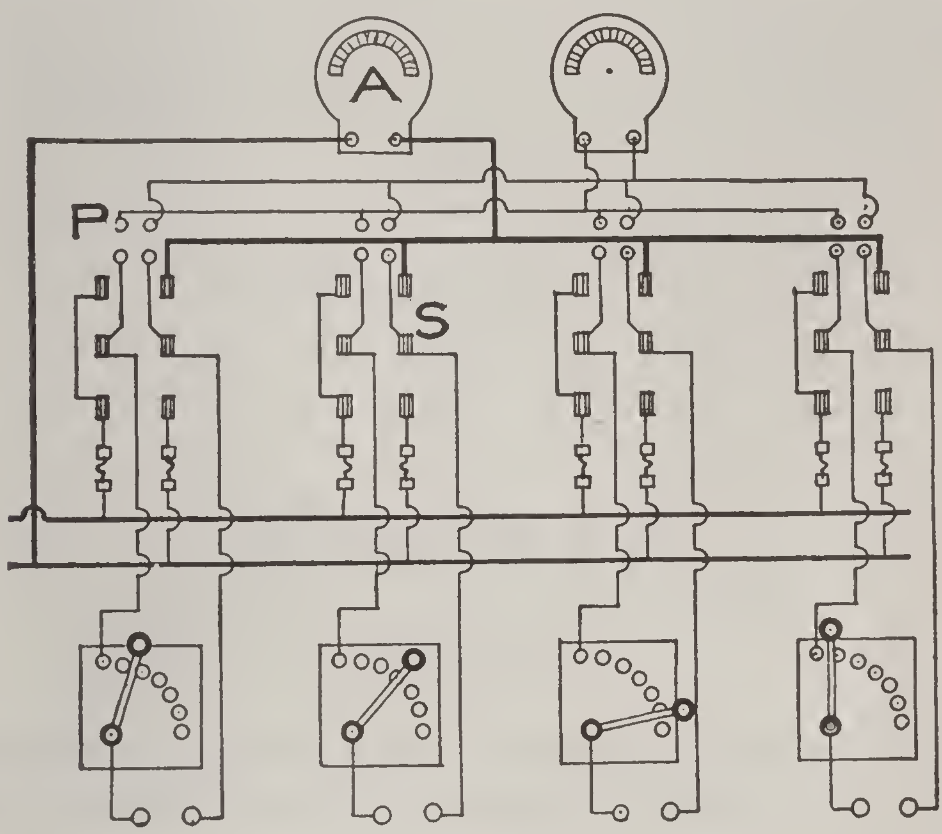


FIGURE 190c.

An end cell switch as sometimes used is shown in Figure 190d. This switch avoids short circuiting the cells while changing from one to the other, and also avoids opening the circuit entirely. The arm A makes the permanent connection, but while it is moving from one segment to the other the other arm carries the current through R.

The Cooper Hewitt Mercury Rectifier, adapted to rectifying alternating currents for the purpose of charging storage batteries, is shown diagrammatically in Figure 190e. B is a glass bulb which carries two electrodes at its upper extremity and a quantity of mercury in the bottom. The globe is further filled with mercury vapor which posseses the peculiarity

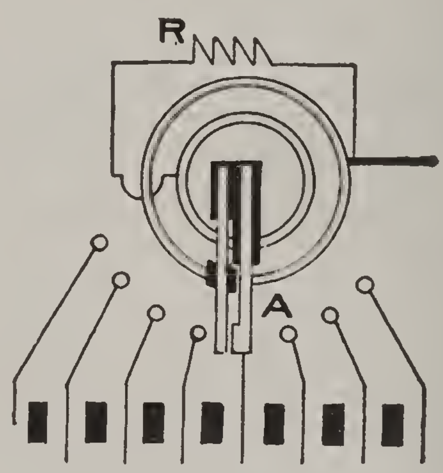


FIGURE 190d.

that it allows current flow from the upper electrodes P into the lower, but does not allow a reversal of this current.

In the bottom of the bulb there are also two electrodes, one in the mercury and the other a little above it. In order to start the operation it is necessary to tilt the bulb sufficiently so that the mercury bridges the two lower electrodes. This starts current flow through the auxiliary wires R. When the bulb is allowed to return, this circuit is interrupted and the current from whichever of the two upper electrodes

happens to be positive at the time continues in its place. Should the current ever cease entirely, even for an instant, the bulb would require to be tilted again. In order to avoid this occurrence the reactance E is provided; this produces a phase difference between the impulses in the supply circuit and those

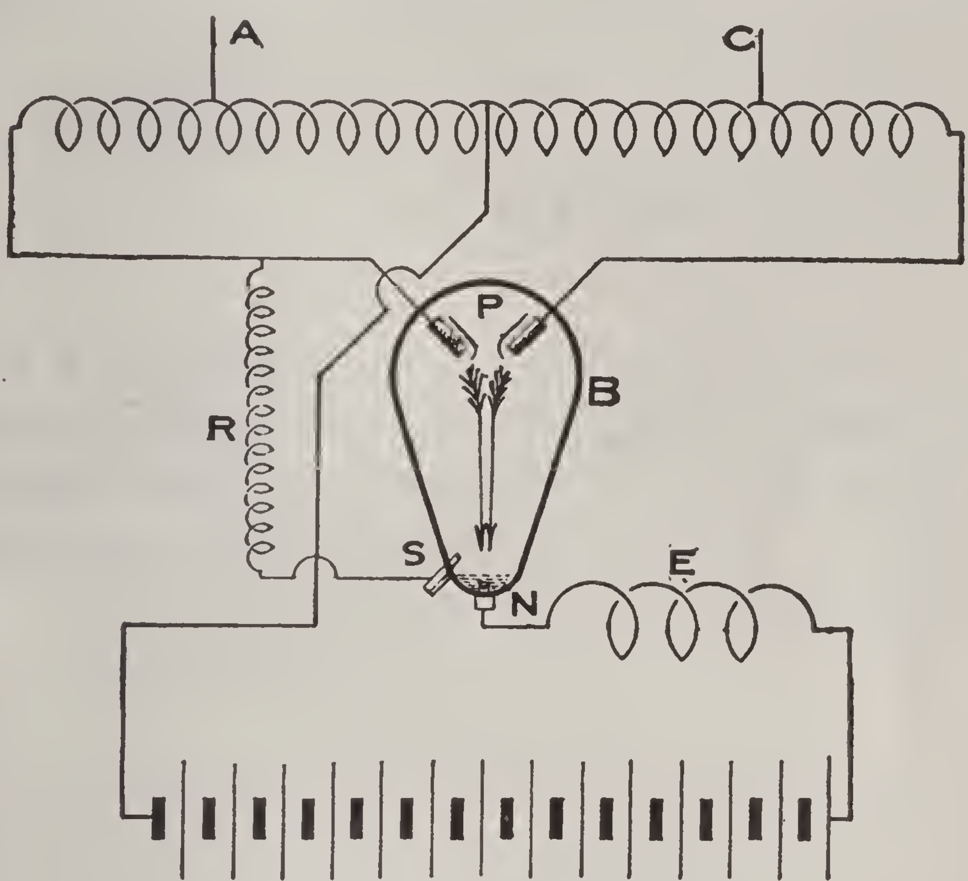


FIGURE 190e.

passing into the battery so that the currents overlap, and the current from one electrode does not cease until that from the other has been started. The alternating current supply is connected at A C.

Figure 190f shows a small storage battery connected to be charged from a series arc circuit. While

the switch 1 remains in the position shown no current passes through the battery. If the switch is pulled downward part of the current passes through the resistance R and part of it through the battery. The dif-

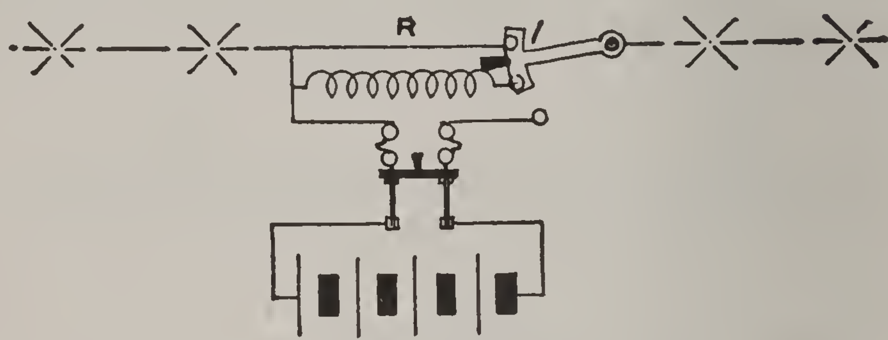


FIGURE 190f.

ference of potential existing at the terminals of R will be equal to the product of the resistance of R and the current flowing. This must always be a little greater than the E. M. F. of the battery or the battery will discharge through the resistance.

CHAPTER XIX.

TESTING.

Figure 191 is designed to illustrate a method of testing out rough wiring when lights or fixtures are to be connected. All wiring may be considered concealed except the ends at outlets, and it is assumed that nothing is known of how the wiring is run in.

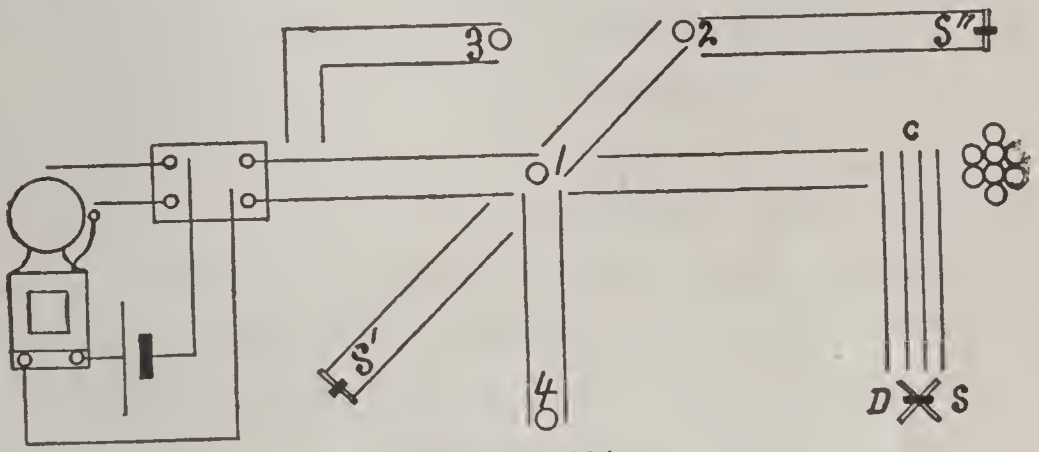


FIGURE 191.

The first step is to separate all wires at outlets, so there may be no wrong connections. Next connect an ordinary bell and battery as shown in the figure and fuse up the circuit. If the bell now rings, there must be a short-circuit in the wiring leading direct from the cutout, since we have disconnected all other wires. To locate this it will be necessary to get access to the wiring, and it may be necessary to tear off plaster or break into walls. Oftentimes it is better to abandon a circuit with such trouble as this and

run in a new one. If the circuit is found clear, the next step is to temporarily bring together the bare ends of all the wires found at any of the outlets until a ring from the bell is obtained. When a ring is obtained it will indicate that the circuit feeds direct to this outlet from the cutout. Next pick out at this outlet the two wires which together produce a ring. These two wires come direct from the cutout, and may now be marked as such.

In the figure it is intended that the light 1 shall be controlled by the switch S′, and the light 2 by the switch S″; the lights 3 and 4 are not provided with switches, but the large chandelier C is to be controlled by the double-pole switch DS.

The next step will be to find the two wires leading to switch S′. To accomplish this, close the switch and bring any two of the wires found at outlet 1 in contact with those coming from the cutout; when the proper wires have been thus connected the bell will ring. One of the switch wires may now be connected permanently to one of the circuit wires coming from the cutout, while the other is to be connected to one side of the lamp or fixture. The other wire coming from the cutout goes to the other side of the lamp or fixture. Lamp 1 is now completely connected and under control of switch S′. The quickest way to find the proper connections for lamp 2 and switch S″ is by bunching all the wires at 2, and then trying at 1, any two wires to those coming from the cutout

until the bell rings. The two wires which cause this ringing lead direct to lamp 2, and may now be connected to the wires leading from the cutout, care being taken that they are connected so as not to come under control of switch S′. Next, separate the wires at 2, and find those which when brought together cause the bell to ring; one of these must be connected direct to the lamp or fixture, while the other is connected to one of the remaining wires. This leaves one wire, and it connects to the other side of the lamp and completes the connection of lamp 2 and switch S″. The four remaining wires at 1 may be found in a similar manner, care being taken that they are also connected behind the connections of switch S′. Two of the six wires at outlet C may now be connected direct to those coming from outlet 1. After this, go to switch DS and find the wires coming from outlet 1 and the cutout (by ringing the bell), and connect them to the proper points on the switch. The remaining wires connect to the other pole of the switch and to the chandelier. The wires leading to lamp 3 may be doubled up under the screws of the cutout terminals.

For testing of this kind the bell shown is the most convenient instrument, since it is audible at quite a distance, and a circuit as described often extends through several rooms. A magneto may also be used, with an assistant to turn the crank, or if the circuit at the cutout is short-circuited the wireman may

carry it with him, making connections wherever he wishes to test. If the cutout center is "alive" a lamp may be placed instead of one of the fuses, and the wireman may carry another with him for testing. A galvanometer or telephone receiver may also be used in this way, the battery alone being connected at the cutout center.

Figure 192 shows the main and branch wiring of a two-wire incandescent system, all complete and ready for final test and connection. In the first place it is necessary to close all the switches and insert all fuses, and a test for short circuits or faulty insulation between opposite poles may then be made by placing a lamp L in circuit in place of one of the main fuses. If current is now thrown on the lamp will light in case there is any serious defect in the insulation between opposite polarities in any part of the system. In case there are any two or three-way switches controlling lights from several places, it will be necessary to turn one of these on each circuit after the first test has been made and then make another test—since one cannot well be certain whether such switches close a circuit or not unless a lamp can be seen to burn. It will also be advisable to do this with single and double pole switches, and may often be easier than removing covers from snap switches to see whether they are on or off. Snap switches will often indicate by the sound of the snap whether they are on or off, but this is not always reliable.

If a more thorough test than that given by the lamp is required, it may be made with any one of the four instruments shown. The voltmeter may be connected in place of the lamp. If the system is perfect the voltmeter will indicate nothing, while if a short-

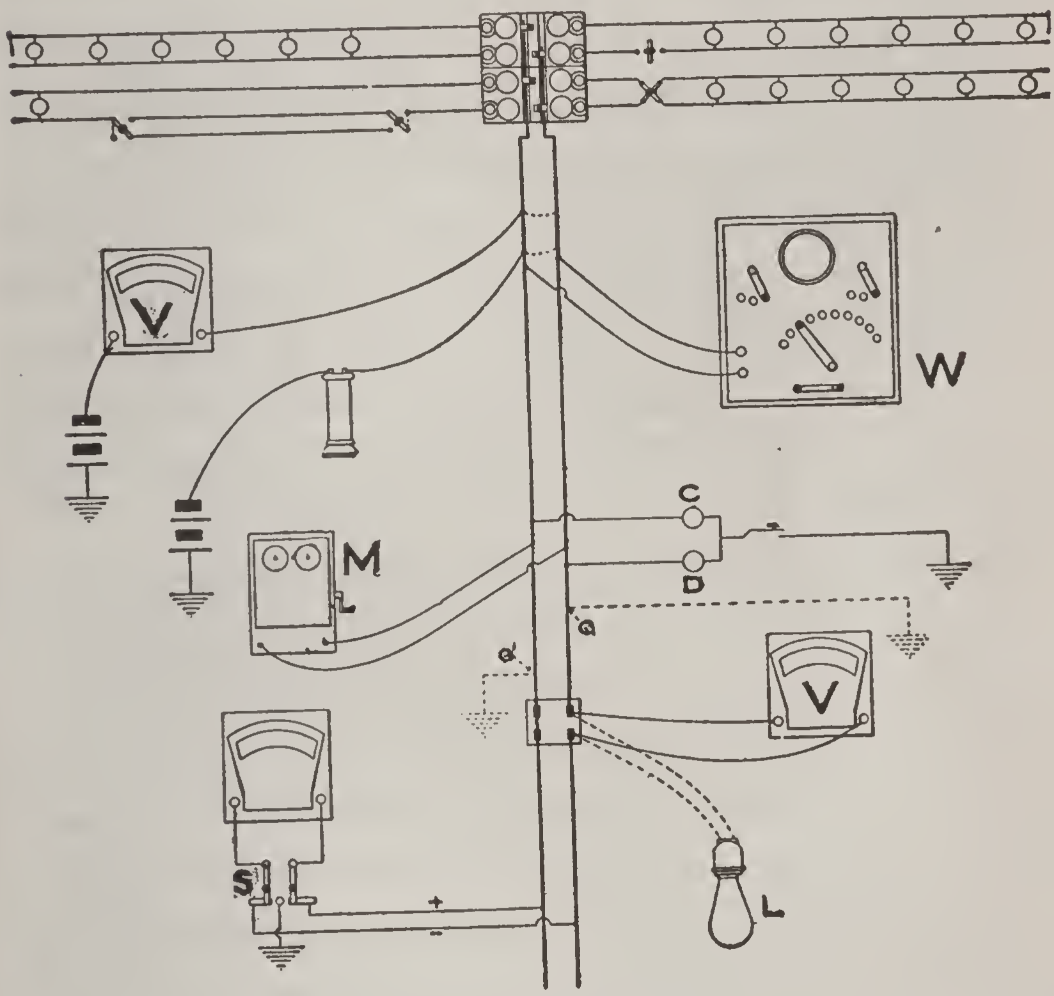


FIGURE 192.

circuit exists it will indicate the full pressure. A telephone receiver may also be used in the same way, if properly wound, and if the system contains no lead-covered wires or iron pipe and is not too large. If the Wheatstone bridge W, or magneto M is to be

used for this test, both main fuses must be removed and connection made to both wires as shown with these instruments. Lead-covered wire, or wire in iron pipe, will also interfere with testing by a magneto, a ring sometimes being obtained when the insulation of the system is perfect.

The figure also shows the voltmeter V and the telephone receiver fitted up with battery to test the insulation resistance to earth of lines having no current; the same connections may be made with the magneto or Wheatstone bridge, and both main wires may be connected at once as shown by dotted lines. More detailed explanation and formulas for testing with the voltmeter and Wheatstone bridge will be given further on.

When it is desired to ascertain the current passing along the mains, an ammeter may be connected in place of voltmeter V as shown. To test the insulation resistance accurately, the system should not be alive, although approximate tests may be made with a voltmeter or ground detector lamps connected as shown in Figure 192. This method of testing live circuits is practical only on small systems, since the system cannot be subdivided, and the indications are accurate only so long as defects are confined to one side of the line. With large three-wire systems it is quite usual to have the neutral wire grounded, and these methods could not be used at all.

In Figure 192 there are shown two ground de-

tector lamps C and D, and by means of a key or switch the wire between them may be connected to ground. As long as this key is not brought in contact with the ground wire, both lamps burn dimly in series and with equal brilliancy, and if no ground exists in any part of the system, depressing the key will not affect the lamps. Should, however, a ground exist, say at G, closing the key will establish a path through the ground and through lamp C to the opposite side of the circuit. If the ground is of very low resistance the lamp C will burn at full candle power, while D will not burn at all. Should the ground be of high resistance there will be but little difference in the brilliancy of the lamps.

The connections of the voltmeter are based on the same principle. The switch S moved one way makes connection with the positive pole through the voltmeter to the ground, and moved the other way makes connection with the negative pole through voltmeter to ground. In the position shown the switch is clear of the ground, and connects the voltmeter to the lighting mains so as to obtain full pressure. The formula for use with the voltmeter when the exact value of the resistance is to be determined is $X = R \left\{ \frac{E-E'}{E'} \right\}$ where E is the full voltage of the battery or other source of current as indicated on the voltmeter, E′ is the reduced reading obtained through the voltmeter and the resistance to be measured, and R the

resistance of the voltmeter, X being the value of the unknown resistance. This formula is based on the supposition that the voltmeter and the resistance to be measured are in series, and that all current passing through the resistance being measured also passes through the voltmeter.

Referring to Figure 192, so long as G is the only defect on the system allowing current to flow, the above formula will give us the correct resistance; as soon, however, as G′ is introduced the formula becomes unreliable, since G′ is a shunt around the voltmeter and robs it of current. The current passing through the voltmeter no longer depends only on the voltmeter resistance and that of G, and therefore the readings can no longer be used as a basis of calculations. As a matter of fact, if the voltmeter test on a live system as shown in the figure indicates a low ground on one side, as, for instance, G′, it will usually show the other side very high. The ground detector lamps are subject to the same limitations, but although they and the voltmeter cannot be relied upon for accurate testing, both are very useful when arranged so that tests can be made several times per day, so as to give means of detecting a ground as soon as it comes on.

In Figure 193 is given a diagram of the Wheatstone bridge. This instrument is generally used where accurate measurements of resistance are to be made, and on account of its wide range it is the most

useful instrument for this purpose. It will be seen that current from the battery entering at 1 has two paths open to it, one through B and X and the other through A and R, to the other pole of the battery. If the resistances A and B are equal, then an equal quantity of current will pass through each to the points 2 and 3 respectively. If the resistances R and X are also equal (though they may be much greater

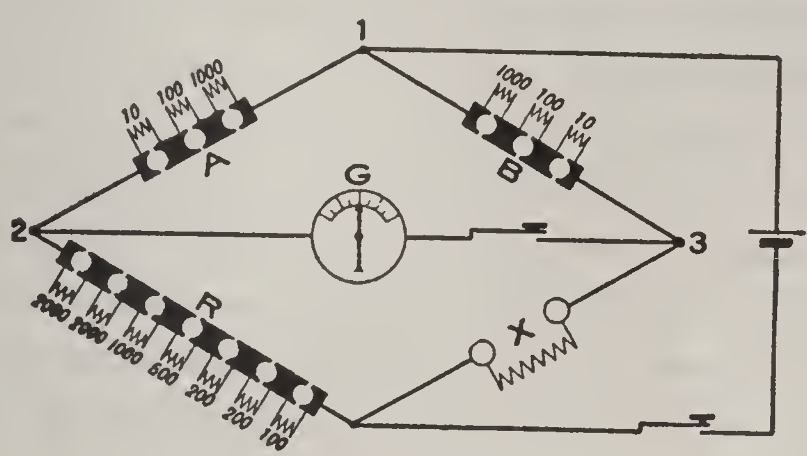


FIGURE 193.

or smaller than A and B) they will also carry away equal quantities of current. Under these conditions no current will pass through the galvanometer G.

If the resistance of A is made ten times as great as that of B, then A will carry only one-tenth as much current to 2 as B will carry to 3; and if R is made ten times as high as X, then R will carry away all the current from 2, while X takes away all current from 3, and still no current will flow through the galvanometer. So long as A is to R as B is to X, no current will pass through the galvanometer. When-

ever this relation is disturbed, some current will pass through the galvanometer, either from 2 to 3 or 3 to 2. If X is entirely open, all the current flowing through B to 3 will pass through the galvanometer to 2; and, again, if R is of higher resistance than X, while A and B are equal, some current will pass from 2 through the galvanometer to 3.

To make the resistance of A, B and R variable, brass plugs are provided which may be inserted in the openings shown so as to form a shunt to the resistance bridged around the opening. In each of the proportional arms A and B two openings are always plugged, and the one unplugged is the resistance through which the current must pass. In R all plugs are removed to get the total resistance, while to get the lowest resistance all openings but the lowest are plugged.

To measure any resistance proceed as follows: If the unknown resistance connected at X is not greater than the total of R, or smaller than any one plug in R, A and B may be plugged equal; for instance, plugs inserted in the openings 1000 and 100 on each arm, leaves on each side ten ohms in circuit and leaves the greatest battery strength for the galvanometer. Now plug R so the resistance will be quite low and press the key; if this gives any deflection note whether it is to the right or left. If a decided deflection has been obtained, remove a number of plugs until the resistance of R is quite high and again press

the key. If the deflection now obtained is in the opposite direction of the former, the value of the resistance is something between the first value of R, and the second, and repeated trials are necessary until no deflection is obtained. No deflection may also be caused by a weak battery. If everything is in order, increasing or lessening R should cause reverse deflections.

When balance is obtained with A and B equal, the sum of the unplugged resistances in R will give the value of X. If X is greater than R, we cannot obtain balance unless B is greater than A; and, conversely, if X is less than the smallest resistance in R, balance cannot be obtained unless B is smaller than A. Whenever balance is obtained, A is to R as B is to X. The values of A, B and R are known, and, since it is a well-known rule of arithmetic that in any proportion the product of the means equals the product of the extremes, we can find the value of X, since

$A \times X = B \times R$, $\frac{B \times R}{A} = X$, or in other words to

find the value of X we must multiply the sum of the unplugged resistances in R by B and divide by A.

If, in Figure 193, A is unplugged to equal 10 and B to 1000, when balance is obtained X will equal 100 times R. If B is unplugged to equal 10 and A at 1000, X will equal 1-100 part of R. The total range of the resistance that can be measured by the arrange-

ment shown in this figure is from 1 ohm to 600,000 ohms.

Figure 194 shows one commercial form of the Wheatstone bridge. In this form movable arms are used to adjust the resistance instead of plugs. The

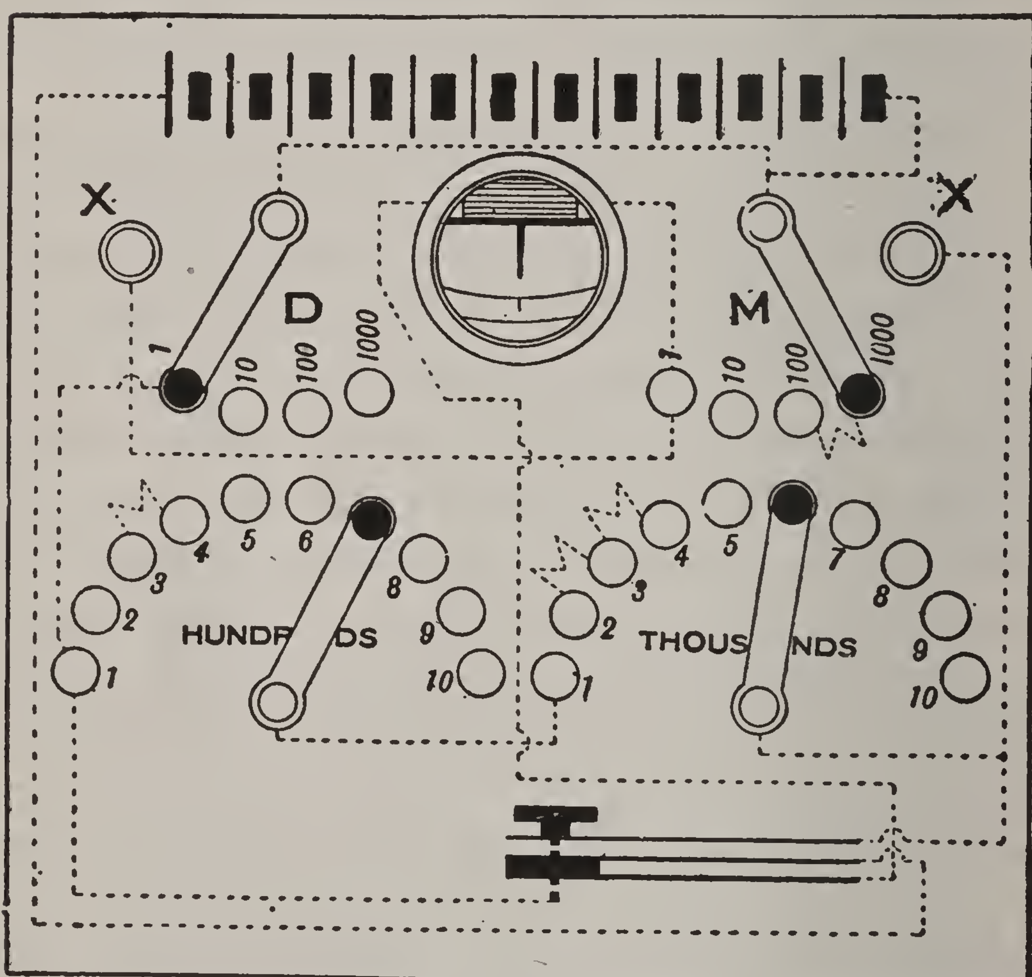


FIGURE 194.

resistance to be measured is connected to the binding posts marked X, and when balance is obtained the sum of the resistances indicated by the lower arms is divided by D and multiplied by M. The key is ar-

ranged to close the battery circuit before closing the circuit through the galvanometer. This is important, especially where inductive resistances such as the coils of electro-magnets are to be measured, and prevents inductance and discharge of these magnets from disturbing the galvanometer reading.

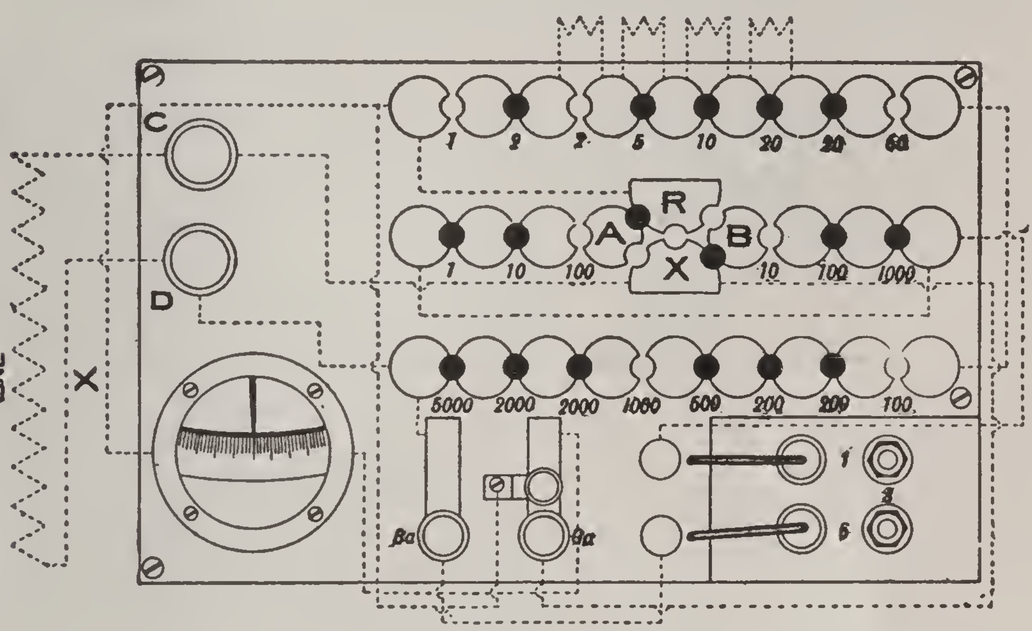


FIGURE 195.

Figure 195 shows another form of Wheatstone bridge, and Figure 196 a diagram of the connections. With this form the resistance to be measured is connected at X, and if it is greater than R the two plugs in the center are arranged as shown in black. When balance is obtained X equals the sum of the unplugged resistances in R multiplied by B and divided by A. With the plugs arranged in the opposite holes between A X and B R, X equals the unplugged resistances of R multiplied by A and divided by B.

As will be seen from Figure 193 the multiplying proportional coil is the one in series with the unknown. In this form of bridge it is possible to place either one of the coils in series with the unknown and hence we may use either one to multiply and the other to divide. This greatly increases the range of the instrument with the same amount of resistance.

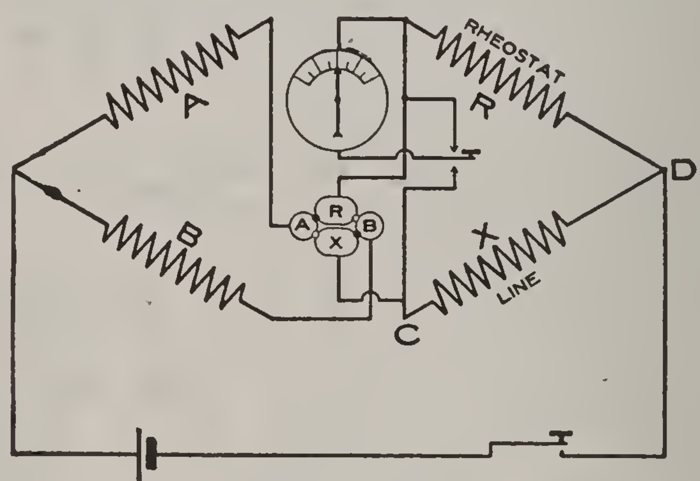


FIGURE 196.

With a plug inserted between R and X, the other two plugs being left out, the box may be used as a straight resistance box. The galvanometer key has a back contact which closes the galvanometer circuit on itself when released, and tends to stop the needle from swinging.

Oftentimes these boxes are not equipped with battery, and instead have two binding posts to which battery may be connected. If the battery in either of the above were connected at X the galvanometer needle could be made to deflect in one direction only.

CHAPTER XX.

LIGHT.

The intensity of the light varies as the square of the distance from the source. This is rigidly true only at such distances where the source of light may be considered as a mathematical point having no physical dimensions. Thus the intensity of an electric light is not four times as great at a distance of two inches as at four inches.

A 16 candle-power lamp is usually allowed for every 100 square feet in ordinary rooms, when not suspended more than seven feet from the floor. With dark colored walls, or where a very bright light is desired, more lamps should be provided.

The efficiency of lamps varies greatly with different candle-powers, a fair approximation being given below:

32	candle-power	lamp	requires	from	100	to	110	watts
16	"	"	"	"	50	"	56	"
8	"	"	"	"	30	"	33	"
4	"	"	"	"	19	"	21	"

After lamps have been used for some time the efficiency is reduced somewhat and the current consumption increased.

The candle-power of any incandescent lamp increases much more rapidly than the current supplied to it, so that the higher efficiency demands full voltage for the lamp. If long life is desired they should be operated at low voltage. Below is given a table, taken from the General Electric Company bulletin, showing the variation in candle-power and efficiency of standard 3.1 watt lamps due to variations in voltage:

Percent of normal Voltage.	Percent of Normal Candle-Power.	Efficiency in Watts per Candle
90	53	4.68
91	57	4.46
92	61	4.26
93	65	4.1
94	69½	3.92
95	74	3.76
96	79	3.6
97	84	3.45
98	89	3.34
99	94½	3.22
100	100	3.1
101	106	2.99
102	112	2.9
103	118	2.8
104	124½	2.7
105	131½	2.62
106	138½	2.54

Example: Lamps of 16 candle-power, 105 volts, and 3.1 watts, if burned at 98 per cent. of normal voltage, or 103 volts, will give 89 per cent. of 16 candle-power, or 14¼ candle-power, and the efficiency will be 3.34 watts per candle-power.

In Figure 197 the various curves show the relation between the candle-power and voltage, current and watts in an incandescent lamp, the curves having been plotted from a 100-volt, 16 c. p. lamp. Taking the curve marked Volts and C. P. it will be seen that at 70 volts the c. p. was at 2, while at 100 volts the c. p. was at 15. As the voltage rises the candle-power increases very rapidly, reaching 25 c. p. at 110 volts and 55 c. p. at about 127 volts.

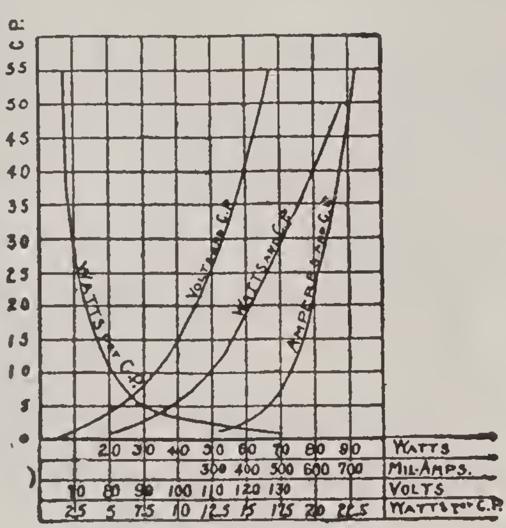


FIGURE 197.

The upper or positive carbon of an arc lamp burns away twice as fast as the negative with continuous currents, but only about 8 per cent. faster with alternating currents.

To get full benefit out of the carbons they should be protected from gusts of wind, as these often blow out the arc and cause rapid consumption of the carbons.

A very simple method of comparing the candle-powers of different lamps is that known as Bunsen's. Set up the lamps to be compared, and, taking a piece of paper with a grease spot on it, adjust it between the two lamps until the spot becomes invisible. The candle-powers of the two lamps are then in the same proportion as the squares of the distances from the paper.

The absorption of light by globes is given as follows:

Clear Glass, 10 per cent. Holophane, 12 per cent. Opaline, 20 to 40 per cent. Ground, 25 to 30 per cent. Opal, 25 to 60 per cent.

An arc light gives out from one-twentieth to one-fortieth as much heat as gas light of equal candle-power.

An incandescent light gives out from one-fifth to one-tenth as much heat as a gas jet of equal candle-power.

One 5-foot gas burner (16 c. p.) vitiates as much air as four men.

CHAPTER XXI.

WIRING TABLES.

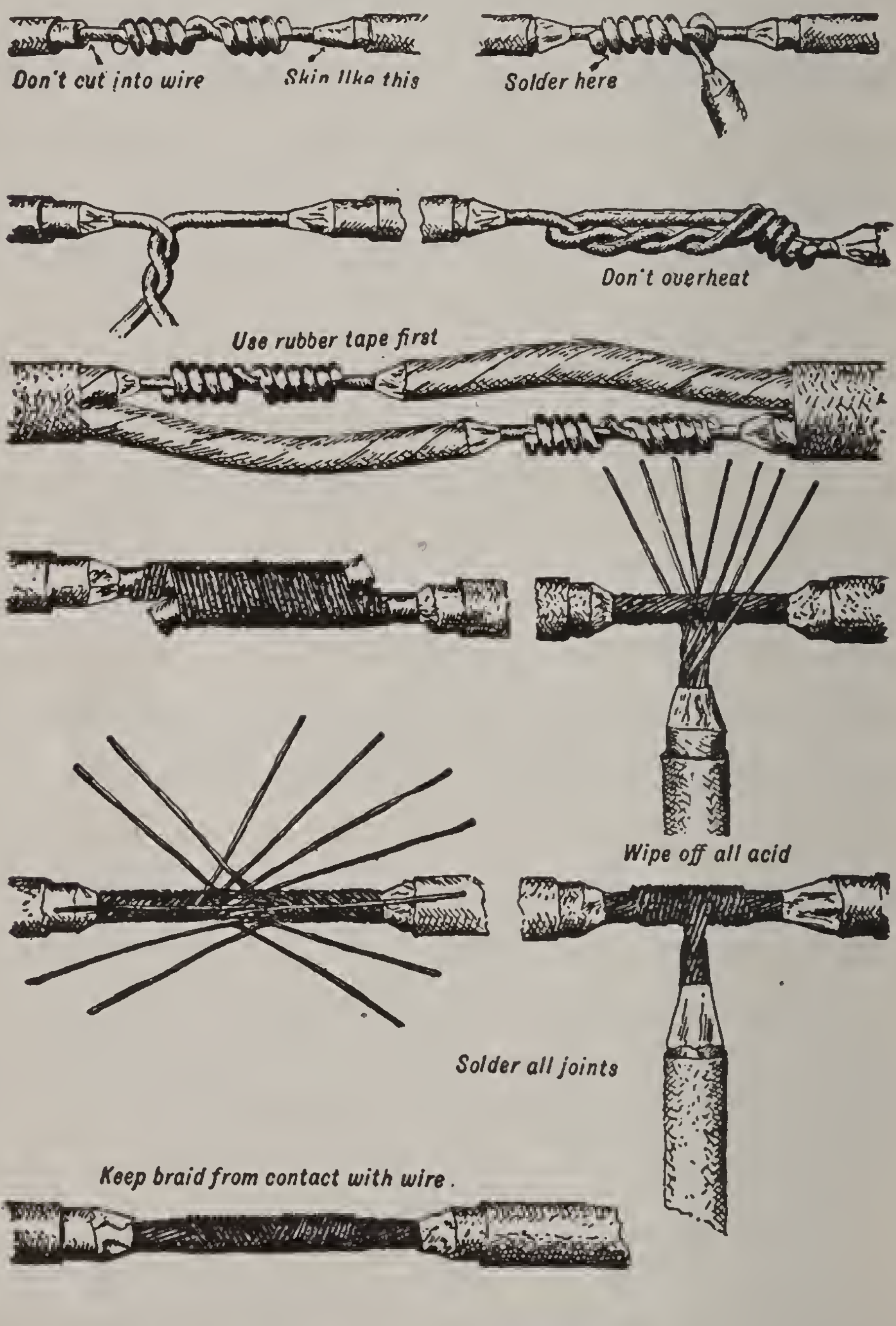
The wiring table No. 1 is arranged in the following manner: For each size of wire and each voltage considered there is given (under the proper voltage and opposite the number of the wire under the heading B. & S.) the distance it will carry 1 ampere at a loss of 1%. The same wire will carry 2 amperes only half as far at the same percentage of loss and again will carry 1 ampere twice as far at double the percentage of loss.

From these facts we deduce the rule of this table which is: Multiply the distance in feet (one leg only) by the number of amperes to be carried and divide the result by the percentage of loss to be allowed. Take the number so obtained and under the proper voltage find the number nearest equal to it. Opposite this number under the heading B. & S. will be found the size of wire required. To illustrate: We have 22 amperes to carry a distance of 135 feet and the loss to be allowed is 3 per cent. at 110 volts.

$$22 \times 135 = \frac{2970}{3} = 990$$

We take the number 990, turn to column for 110 volts, and find 841, which is not sufficient. The next above it

is 1060, which corresponds to No. 7 wire. With this wire our loss will be slightly less than 3%, while with No. 8 it would be somewhat in excess of 3%.



For three-wire systems using 110 volts on each side, the column marked 220 volts should be used. The

column marked 440 volts is provided for three-wire systems using 220 volts on each side. The sizes determined will be correct for all three wires in both cases.

The columns at the right, marked motors, are arranged in the same way, the only difference being that, for greater convenience, they are figured in H. P. feet instead of ampere feet. For this reason we multiply the distance in feet by the number of horsepower to be transmitted and divide by the percentage of loss, all other operations remaining the same as under lights.

When any considerable current is to be carried only a short distance the wire indicated by the desired loss will very likely not have sufficient carrying capacity; it is, therefore, always necessary to consult the table of carrying capacities.

Light and Motor Wiring Table.—No. 1.

Lights in Amperes. Volts.				B. & S. Gauge.	Car. Cap.	Motors in Horse Power. Volts.				Resis. per foot
52	110	220	440			110	220	440	500	
98	209	418	836	14	12	28	112	448	579	.002628
124	263	526	1052	13	....	35	140	560	724	.002084
158	333	666	1332	12	17	44	176	704	910	.001653
200	420	840	1680	11	....	56	224	896	1159	.001311
250	529	1058	2116	10	24	70	280	1120	1449	.001040
314	665	1330	2660	9	....	88	352	1408	1821	.000824
397	841	1682	3364	8	33	112	448	1792	2318	.000654
501	1060	2120	4240	7	....	141	564	2256	2918	.000519
634	1338	2676	5352	6	46	178	712	2848	3684	.000411
798	1687	3374	6748	5	54	224	896	3584	4636	.000326
1000	2124	4248	8496	4	65	283	1132	4528	5858	.000259
1271	2683	5366	10732	3	76	357	1428	5712	7389	.000205
1595	3374	6748	13496	2	90	449	1796	7184	9294	.000163
2011	4264	8527	17054	1	107	568	2272	9088	11757	.000129
2543	5392	10784	21568	0	127	718	2872	11488	14762	.000102
3228	6790	13580	27160	00	150	905	3620	14480	18733	.000081
4053	8594	17188	34376	000	177	1145	4580	18320	23701	.000064
5090	10784	21568	43136	0000	210	1437	5748	22992	29745	.000051
6032	12790	25580	51160	250000	235	1696	6784	27136	35107	.0000431
7222	15277	30554	61108	300000	270	2036	8144	32576	42145	.000036
8441	17857	35714	71428	350000	300	2368	9472	37888	49017	.0000308
9629	20370	40740	81480	400000	330	2714	10856	43424	56179	.000027
10833	22916	45832	91664	450000	360	3054	12216	48864	63217	.000024
12093	25581	51162	102324	500000	390	3393	13572	54288	70235	.0000215
24074	50925	101850	203700	1000000	650	6786	27144	108576	140470	.0000108
48148	101851	203702	407404	2000000	1050	13573	54292	217168	280961	.0000054

For lights, find the ampere feet (one leg) and divide by the per cent. of loss. Under the proper voltage find the number equal to this or the next larger; opposite this number in the column marked B. & S., will be found the size of wire required.

For Motors, proceed in the same way, using H. P. feet instead of ampere feet.

It may often be desired to find the loss in an established circuit carrying a certain load. This may readily be determined from this table by observing the following rule: Find the number of ampere feet and, selecting the column headed by the proper voltage, divide by the number opposite the size of wire used. For example, we have a No. 10 wire carrying 24 amperes a distance of 90 feet at 110 volts, $24 \times 90 = 2160$. Opposite No. 10 in the column marked B. & S. gauge and under 110 volts we find 529, $\frac{2160}{529} = 4$ and a very small fraction, which is the percentage of loss occurring on this line.

It is often necessary to reinforce mains which have become overloaded. It is quite usual though often very incorrect, to choose by the table of carrying capacities a wire of such size that the rated capacity of it and the wire to be re-enforced shall be equal to the load. Small wires have proportionately a much greater radiating surface than larger ones and therefore their carrying capacity is proportionally great-

er. In order that a wire connected in parallel with another wire shall carry a certain current, its circular mils, must be equal $\frac{\text{C. M.} \times a}{A}$ where C. M. stands for the cross-section of the larger wire in circular mils and A for the current to be carried by it, while a is the current to be carried by the extra wire. Table No. 2 is calculated from this rule and shows the size of wire necessary to re-enforce another overloaded to a certain per cent. as indicated in the top row. For instance, a 0000 wire overloaded 40% requires re-enforcement by a No. 1; a No. 3 wire overloaded 20% requires a No. 10 wire. Where large wires are re-enforced in this way by smaller ones great care must be taken that the larger wire cannot be accidentally broken or disconnected, since in such a case the whole load would be forced over the smaller wire and would likely result in a fire. The two wires should be securely soldered together.

No. 2.

Amperes.	B. & S.	10%	20	30	40	50	60	70	80	90	100
210	0000	6	4	2	1	0	00	000	000	0000	0000
177	000	8	5	3	2	1	0	00	000	000	000
150	00	9	6	4	3	2	1	0	0	00	00
127	0	10	7	5	4	3	2	1	1	0	0
107	1	10	8	6	5	4	3	2	2	1	1
90	2	11	9	7	6	5	4	3	3	2	2
76	3	12	10	8	7	6	5	4	4	3	3
65	4	14	11	9	8	7	6	5	5	4	4

No. 3.

Numbers B. & S. Gauge.	Diameters in Mils.	Areas in Circular Mils. C.M.=d^2	Weights. 1000 feet.	Weights. Mile.	Ohms per 1000 feet
0000	460.	211,600.	641.	3,382.	.051
000	410.	168,100.	509.	2,687.	.064
00	365.	133,225.	403.	2,129.	.081
0	325.	105,625.	320.	1,688.	.102
1	289.	83,521.	253.	1,335.	.129
2	258.	66,564.	202.	1,064.	.163
3	229.	52,441.	159.	838.	.205
4	204.	41,616.	126.	665.	.259
5	182.	33,124.	100.	529.	.326
6	162.	26,244.	79.	419.	.411
7	144.	20,736.	63.	331.	.519
8	128.	16,384.	50.	262.	.654
9	114.	12,996.	39.	208.	.824
10	102.	10,404.	32.	166.	1.040
11	91.	8,281.	25.	132.	1.311
12	81.	6,561.	20.	105.	1.653
13	72.	5,184.	15.7	83.	2.084
14	64.	4,096.	12.4	65.	2.628
15	57.	3,249.	9.8	52.	3.314
16	51.	2,601.	7.9	42.	4.179
17	45.	2,025.	6.1	32.	5.269
18	40.	1,600.	4.8	25.6	6.645
19	36.	1,296.	3.9	20.7	8.617
20	32.	1,024.	3.1	16.4	10.566
21	28.5	812.3	2.5	13.	13.283
22	25.3	640.1	1.9	10.2	16.85
23	22.6	510.8	1.5	8.2	21.10
24	20.1	404.	1.2	6.5	26.70
25	17.9	320.4	.97	5.1	33.67
26	15.9	252.8	.77	4.	42.68
27	14.2	201.6	.61	3.2	53.52
28	12.6	158.8	.48	2.5	67.84
29	11.3	127.7	.39	2.	84.49
30	10.	100.	.3	1.6	107.3
31	8.9	79.2	.24	1.27	136.2
32	8.	64.	.19	1.02	168.5
33	7.1	50.4	.15	.81	214.0
34	6.3	39.7	.12	.63	271.7
35	5.6	31.4	.095	.5	343.6
36	5.	25.	.076	.4	431.6

No. 4.

Table Showing the Currents Which will Fuse Wires of Different Substances.

B. & S. Gauge.	Diam.	Copper.	Aluminum.	German Silver	Iron.
10	102.	333.	246.5	170.	102.3
12	81.	236.	174.4	120.5	72.6
14	64.	165.7	122.8	84.6	50.9
16	51.	117.7	87.1	60.1	36.1
18	40.	81.9	60.7	41.8	25.2
20	32.	58.5	43.4	29.9	18.
22	25.3	41.1	30.5	21.0	12.4
24	20.	28.9	21.5	14.8	8.9
26	16.	20.7	15.3	10.6	6.4
28	12.6	14.5	10.7	7.4	4.5
30	10.	10.2	7.6	5.2	3.1
32	8.	7.3	5.4	3.7	2.3
34	6.3	5.1	3.8	2.6	1.6
36	5.	3.6	2.7	1.8	1.1

CHAPTER XXII.

ELECTRIC SIGNS. FLASHERS. DISPLAY LIGHTING.

Figure 198 gives a diagrammatic view of the Reynolds Flasher for electric signs and displays. The flasher here shown is capable of controlling twelve circuits, each circuit with a single-pole switch. Only

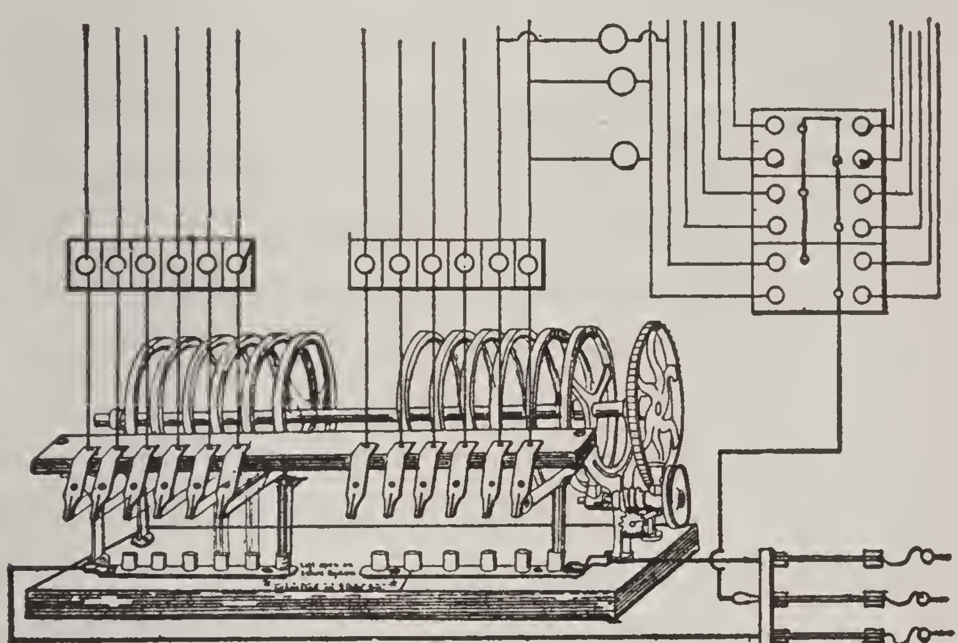


FIGURE 198.

one wire of each circuit passes through the flasher and single-pole fuses are usually installed as near as possible to the flasher. The fuses for the other sides of the circuits may be installed within signs or wherever convenient. The diagram shows flasher ar-

ranged for three-wire circuits. In case of a two-wire installation only one of the mains is led to the flasher and the two sections of the flasher are connected together.

Figures 199 to 204 show the circuits of a flasher for electric signs and displays made by Rawson & Evans of Chicago. This machine is designed to change connections from one circuit to another without ever entirely opening the circuit. From two

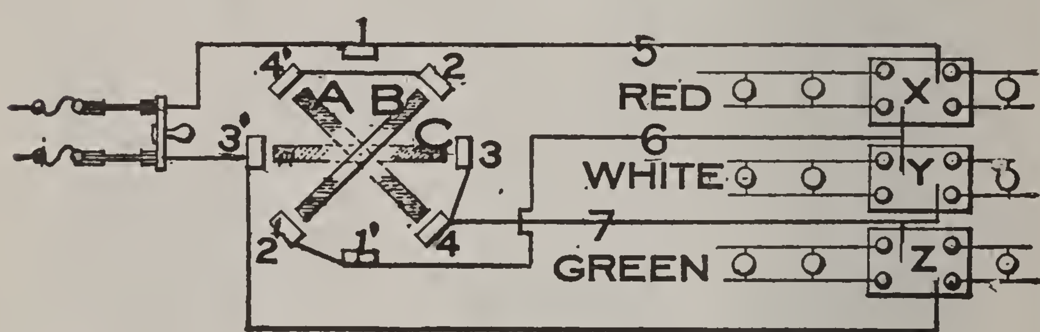


FIGURE 199.

to four groups of lamps are wired in series and the movable arms, A, B, C, Figure 199, short-circuit those groups not in use. During the time of change from one group to another all the groups are in series and most of the current which would otherwise manifest itself in the form of a spark passes through the lamps. The time of open circuit is so very short that it is impossible to hold an arc for any appreciable time. The breaking of the circuit in many places at the same time also lessens the destructive qualities of the arc which occurs.

Figure 199 is a diagram of the flasher as connected to three-color signs; the white lights being arranged to follow after the red and also after the green. Referring to Figure 199, A, B, C, are metal arms insulated from one another but firmly fastened together so as to form one movable piece. As these arms are moved from point to point they connect the diametrically opposite terminals, 1, 1′; 2, 2′; 3, 3′; and 4, 4′. In Figure 199 the current passes along wire 5 through the red lights connected to cut-out X, to wire 6, point 2′, arm B to point 2, thence to point 4′, arm A, points 4 and 3 to arm C, back to the other pole of dynamo. So long as the arms remain in this position the r d lights burn and all the others are short-circuited. The next position of the machine brings arm A in contact with points 1 and 1′; current now passes direct from point 1 through arm A to point 1′, wire 6 and the white lights at Y; arm A now forming a short circuit around the red lights. The current passing through the white lights returns over wire 7 to point 3 and arm B (which has also moved) to the other pole of dynamo. The white lights now burn and all others are short-circuited.

The next movement brings arm A in contact with points 2 and 2′ and C to 1 and 1′, leaving no connection between 3 and 3′. The current now passes through arm C from point 1 to 1′; thence to point 2′ arm A, point 2, 4′ arm B to point 4 through the green lights and back to point 3′ and to the other

pole of the dynamo. The green lights now burn while the others are short-circuited.

The fourth position of the arms leaves the space between 4 and 4′ open and the current again passes through one of the arms from point 1 to 1′, wire 6, white lights, wire 7 to points 3, 3′ and back to dynamo. An elementary diagram of those connections is shown in Figure 200. Three of the points, 1, 2, 3, 4, are always short-circuited.

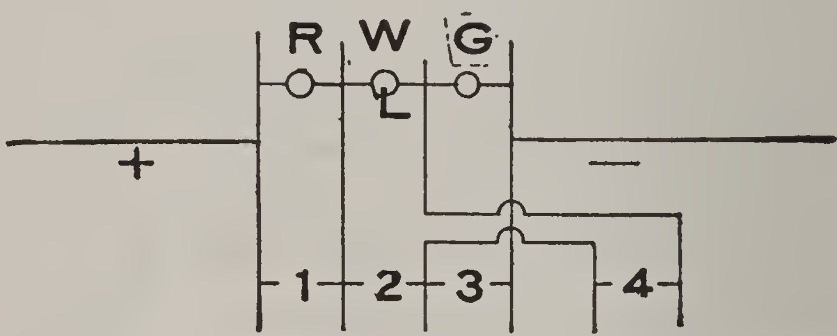


FIGURE 200.

Figure 201 shows the same machine with one of the arms removed connected to control a double-face sign, one side to burn at a time. The current in this case passes from the positive pole of the switch to the upper group of cutouts which represent one side of the sign. The current passing through these lamps continues to point 2′, thence to point 1, arm A, point 1′ and 3, arm B and negative pole of the switch. The next movement brings arm B in contact with point 4′ and current passes along it to 4, thence to 2, arm A to 2′, the lower group of cutouts representing the

other side of sign and back to the negative side of the switch.

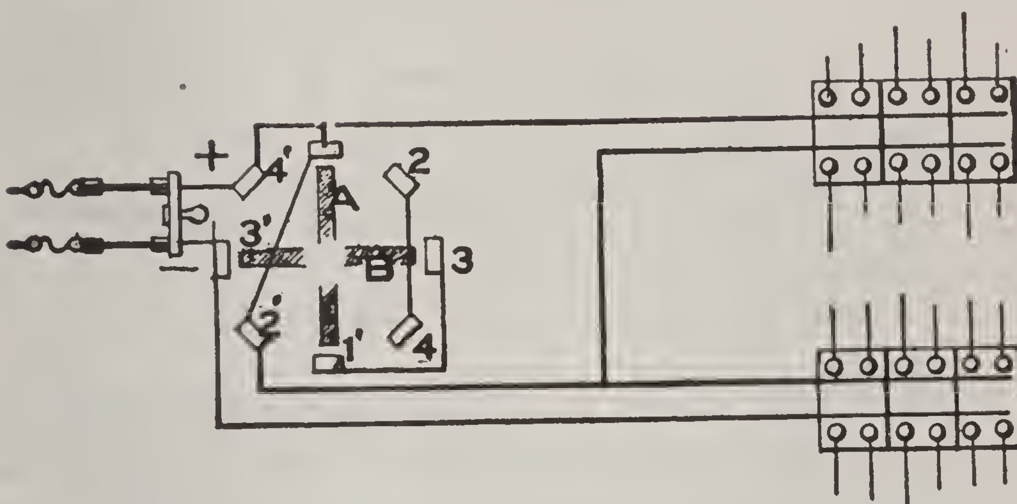


FIGURE 201.

Figure 202 shows connections for four groups of colors, one at a time being illuminated.

In Figures 203 and 204 connections for single and double-pole break are shown.

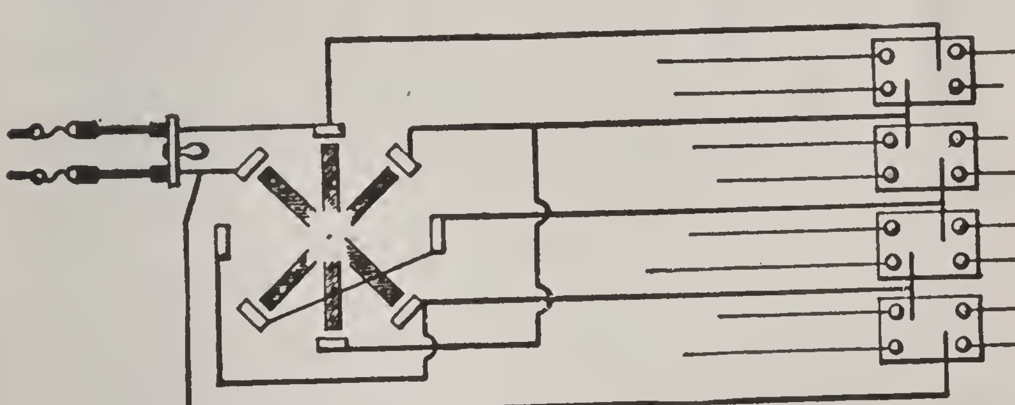


FIGURE 202.

For large installations, in connection with three-wire systems, double-disc machines are used; the positive and neutral wire connecting to one and the negative and neutral to the other.

This machine and the combination of circuits are protected by letters patent.

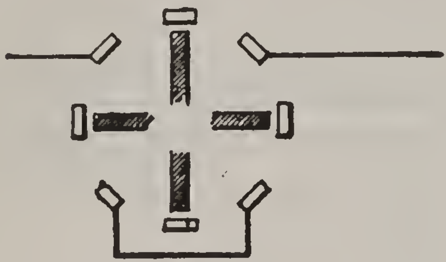


FIGURE 203.

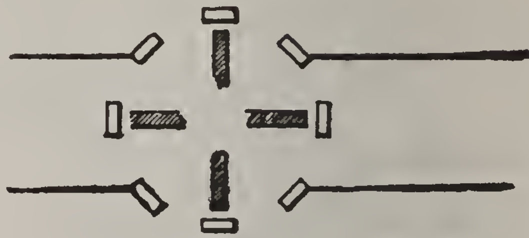


FIGURE 204.

Figure 205 will serve to illustrate the principle of several of the monogram signs. The incandescent lamps L are each set within a metal shield which pre-

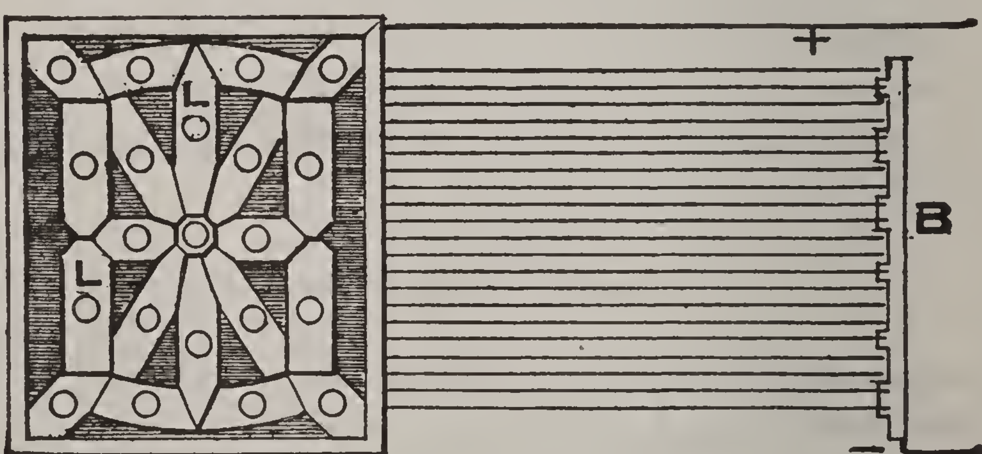


FIGURE 205.

vents the spread of light to any other part of the sign. One common feed wire leads to all of the lamps, and from each lamp a switch wire leads to the machine serving to make the proper connections. Each monogram has the lights within it so distributed that by lighting the proper lamps any letter in the alphabet can be made and a sign, consisting, say,

of 10 monograms, can, therefore, be made to spell out any word or combination of words which does not exceed ten letters.

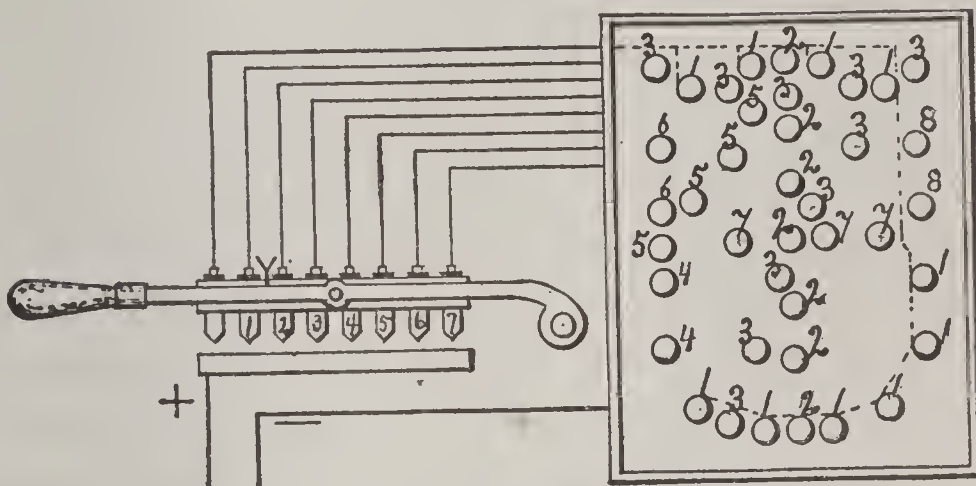
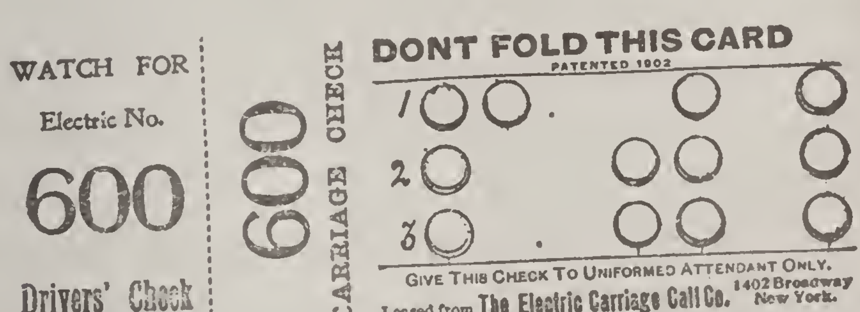


FIGURE 206.

The mechanism used for spelling out words consists of a set of discs for each monogram and these carry brass bars, as shown at B, which serve to energize



the wires leading to the lamps. These bars are cut out as shown and only those sections remaining full make contact with the switch wires.

Figure 206 is a representation of a monogram used

as a carriage call, principally for theatres. In this case only nine wires are used for each monogram and in case the sign is illuminated on both sides each of the nine wires supplies two monograms, one on each side. One wire is a common feed for all of the lamps and the other eight wires serve each to connect a small group of lamps in the monogram. These groups of lamps are so arranged that by a combination of them almost any number from 0 to 9 can be made. To accomplish this a perforated card shown at bottom of this cut is used. The card shown is arranged for a sign consisting of three monograms.

As will be seen the yoke Y carries 8 contact points each of which is capable of making contact and energizing the wire connected to it when the yoke is pressed down upon the current carrying bar beneath it. In order to allow none but the proper points to be connected the card is inserted between the current carrying bar and the yoke. Thus the figure 6 is made by allowing only the points 1, 2, 5 and 7 on the yoke to make connection with the bar below. The 0 is formed by making connection with points 1, 4, 5 and 7. In this figure all of the lamps denoted by the same number are on one circuit. The lamps marked 2, if lighted, will form the figure 1; the lamps 1, 4, 6 and 7 form the figure 6, while 0 is formed by 1, 4, 6 and 8.

A somewhat similar monogram is made by wiring the necessary number of properly distributed lamps

on one or more circuits in the usual manner and then inserting lamps only where required to outline the letter or number wanted, the other openings being covered.

All of these devices are covered by letters patent. The information herein given is intended merely to enable wiremen to intelligently go about connecting them should occasion require.

INDEX

DIRECT AND ALTERNATING CURRENT MOTORS

CONTENTS

ELECTRIC MOTORS

CHAPTER I

DIRECT-CURRENT ELECTRICAL CIRCUITS

Electrical Circuit.—The path in which electricity moves is called the *electrical circuit,* and it is necessary to have a working knowledge of the various properties of electrical circuits and the quantities associated with them in order to completely understand the operation of electrical machinery. Electrical circuits are of numerous forms, but all possess to a great degree the same properties and involve the same quantities. Suppose, for example, a small electric motor is operated from a storage battery, as shown in Figure 1. This combination constitutes an electrical circuit which is typical of all electrical circuits. It contains a source of electrical energy—the battery; an energy transforming device—the electric

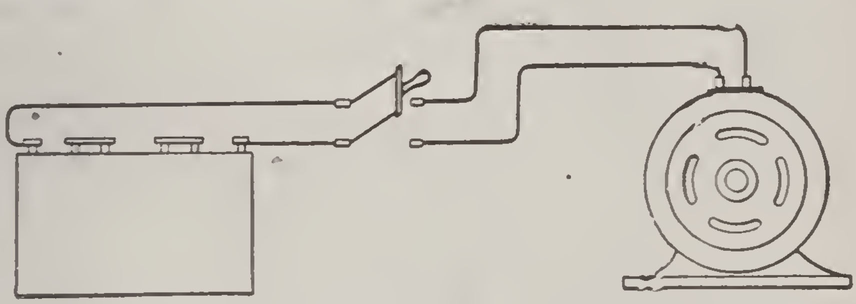


Figure 1.—Typical Electrical Circuit.

motor; and the necessary connecting material—wires and switch. It must be remembered that all electrical circuits are closed on themselves and, like the circumference of a circle, have neither beginning nor end.

Current of Electricity.—The flow of electricity can be compared to the flow of water in a pipe. The flow of water is usually expressed as so many gallons per minute, so many cubic feet per minute, or any combination of volume and time. The flow of electricity is likewise expressed as so many units of quantity in a unit of time. The unit of quantity of electricity is called the *coulomb.* When there is a uniform flow of one coulomb through the circuit each second, there is said to be a unit of current of electricity in the circuit. A flow of one coulomb per second is called an *ampere.*

Resistance of Electrical Circuit.—The opposition offered by a circuit to the free flow of electricity through it is called the *resistance of the circuit,* and it is measured in a unit called the *ohm.* The resistance offered by different materials to the flow of electricity through them varies between wide limits. Those materials which offer a relatively low resistance, such as the metals, are called *conductors;* while those materials which offer a relatively high resistance, such as glass, rubber, dry paper, etc., are called *insulators.*

Electrical Pressure.—The electrical pressure—sometimes called the *electromotive force, electricity moving force, voltage,* or *drop in potential*—causes the electricity to move in the electrical circuit when the circuit is closed, and it is measured in a unit called the *volt.* There are a number of ways of producing an electrical pressure, but the two most common are by

chemical action in the battery, and by electromagnetic induction in the generator.

Ohm's Law for Electrical Circuit.—Dr. G. S. Ohm experimentally discovered that there was a definite relation between the resistance of a circuit, the pressure acting on the circuit, and the current produced. The values of the units in which resistance, pressure, and current are measured are such that the relation may be written as follows:

$$\text{amperes} = \frac{\text{volts}}{\text{ohms}}$$

The current in amperes, the pressure in volts, and the resistance in ohms are represented by the symbols I, E, and R, respectively. Substituting these symbols for the quantities in the above equation gives

$$I = \frac{E}{R} \quad \text{(a)}$$

Other forms in which the above equation may be written are as follows:

$$\text{ohms} = \frac{\text{volts}}{\text{amperes}}$$

$$R = \frac{E}{I} \quad \text{(b)}$$

and

$$\text{volts} = \text{amperes} \times \text{ohms}$$

$$E = I \times R \quad \text{(c)}$$

Examples.—1. The field winding of a direct-current motor has a resistance, under operating conditions, of 30 ohms. What is the value of the field current when the impressed pressure is 110 volts?

Solution.—Substituting the values of pressure and resistance in equation (a) gives

$$I = \frac{110}{30} = 3\frac{2}{3}$$
$$= 3.67\text{— amperes}$$

2. What resistance must an electrical heater have in order that it may take a current of 5 amperes from a 220-volt circuit?

Solution.—Substituting the values of current and pressure in equation (b) gives

$$R = \frac{220}{5}$$
$$= 44 \text{ ohms}$$

Ohm's law holds true for any part of a circuit just the same as it does for the entire circuit; that is, *the pressure over any part of the resistance of a circuit is equal to the product of the resistance of that portion of the circuit and the current.*

Calculation of Resistance.—The resistance of a conductor varies directly as the length and inversely as the area of the conductor; that is, the longer the conductor the greater the resistance and the larger the conductor the smaller the resistance. The resistance of a conductor also depends upon the kind of material of which it is composed. The above relations may be put into the form of an equation as follows:

$$\text{resistance} = \frac{\text{constant} \times \text{length}}{\text{area}}$$

Representing the constant in the above equation by K, the length by l, and the area by A, the equation may be written as follows:

$$R = K\frac{l}{A}$$

The value of the constant K will depend upon the kind of material in the conductor and also upon the units in which the value of the length and the area of the conductor are measured. When the length is measured in feet and the area in circular mils, the value of K is called the *mil-foot resistance* of the material. The area of a conductor in circular mils is equal to the diameter of the conductor in mils multiplied by itself. The mil is equal to the one-thousandth part of one inch. If the area of a conductor in circular mils is known, its area in square mils can be computed by multiplying the value of the circular-mil area by .7854. To change an area in square mils to circular mils divide by .7854. The area of a rectangular conductor in square mils is equal to its area in square inches multiplied by 1,000,000. The values of the mil-foot resistance for some of the more common metals are given in Table I in the Appendix.

Example.—Calculate the resistance of a conductor 500 feet long, having a diameter of 102 mils and composed of a material having a mil-foot resistance of 10.8.

Solution.—Substituting directly in the equation for resistance gives

$$R = \frac{10.8 \times 500}{102 \times 102}$$

$$= \frac{5{,}400}{10{,}404}$$

$$= .519 + \text{ohm}$$

The majority of electrical conductors are circular in cross-section and they are drawn to certain definite sizes. The diameter, area in circular mils, resistance,

etc., for different size copper wires are given in Table II in the Appendix.

Resistance Changes with Temperature.—The resistance of practically all substances changes when there is a change in their temperature. Almost all materials increase in resistance with an increase in temperature, the resistance of some, however, decreases with rise of temperature. The carbon filament lamp when hot has about one-half the resistance it has when cold. Some alloys, such as manganin, experience practically no change in resistance due to change in temperature.

The change in resistance of a material per ohm due to a change in temperature of one degree is called the *temperature coefficient* of the material. Thus, if a copper wire had a resistance of 10 ohms at 32 degrees Fahrenheit and 10.233 ohms at 42 degrees Fahrenheit, its temperature coefficient would be calculated as follows: The total change in resistance is equal to 10.233 − 10, or .233 ohm. This change in resistance is due to a change in temperature of 10 degrees; hence, the change per each degree is one-tenth of this amount, or .0233. This increase of .0233 ohm per degree occurs in 10 ohms, then the change per ohm will be equal to one-tenth of this, or .00233. Hence, the temperature coefficient of the material based on 32 degrees Fahrenheit is equal to .00233. The values of the temperature coefficients for some of the more common materials are given in Table I in the Appendix. These values are all based on an initial temperature of zero degrees centigrade and 32 degrees Fahrenheit, and, if the initial temperature of the conductor does not correspond to these values, its resistance at the freezing temperature should be cal-

culated first; and another calculation should be made to determine its resistance at the second temperature.

Example.—The shunt field coil of a motor has a resistance of 53.5 ohms at 62 degrees Fahrenheit, what will its resistance be at 90 degrees?

Solution.—One ohm at 32 degrees, if raised to a temperature of 62 degrees, will increase in resistance .00233 ohm for each degree rise in temperature, or the total increase for each ohm, in this case, will be equal to $.00233 \times 30$, or .0699. Then the one ohm at 32 degrees will have $1.0000 + .0699$, or 1.0699 ohms at 62 degrees. Since the total resistance at 62 degrees is 53.5 ohms, the resistance at 32 degrees will be equal to $53.5 \div 1.0699$, or 50 ohms. The increase in resistance of each ohm when the temperature rises from 32 degrees to 90 will be $.00233 \times 58$, or .13514; and the resistance of each ohm at 90 degrees will be $1.00000 + .13514$, or 1.13514. The resistance of 50 ohms at 32 degrees will be equal to 50×1.13514, or 56.75— ohms, at 90 degrees.

Series Circuits.—A series circuit is one in which the various elements constituting the circuit are so connected that there is only one path in which the electricity can flow. For example, in Figure 2, two resistances R_1 and R_2 and two dry cells are all connected in series. The total resistance of such a circuit is equal to the sum of the resistances of the different parts of the circuit.

The effective pressure acting in such a circuit as that shown in Figure 2 is equal to the sum of the different pressures provided they are all connected so as to act in the same direction. The terminal of a source of electrical pressure from which the current flows is called the *positive* or *plus terminal* and is always marked in a diagram by means of the sign of addition (+); while the terminal toward which the current flows is called the *negative* or *minus terminal* and is marked in a diagram by means of the sign of

subtraction (−). In the case of the dry cell, the positive terminal is the carbon rod and the negative terminal is the zinc cup, and each is provided with a convenient binding post for making connections. If a number of sources of electrical pressure be connected in series, but in such a way that some of them tend to produce a current through the circuit in one direction and the others in the opposite direction, then the

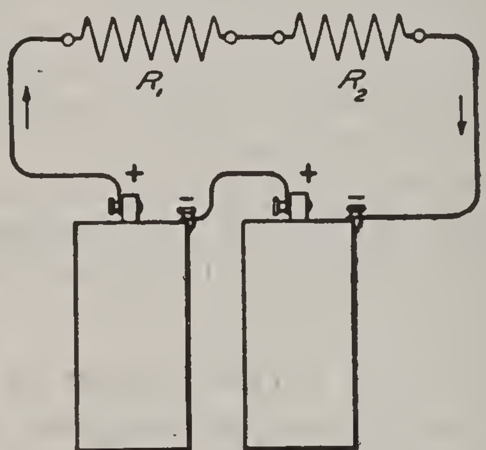


Figure 2.—Series Electrical Circuit.

effective pressure will be equal to the difference between the combined pressures in one direction and the combined pressures in the opposite direction, and the direction of the current will be determined by the difference in the combined pressures.

Example.—Six dry cells, each having an electromotive force of 1.5 volts and an internal resistance of .05 ohm, are connected in series, the positive terminal of one being joined to the negative terminal of the next, etc. This combination of cells is connected to a circuit composed of two coils of wire having resistances of 1 and 3 ohms, respectively, and the connecting leads have a resistance of .2 ohm. What current will be produced?

Solution.—The total internal resistance of the dry cells will be equal to

$$6 \times .05 = .3 \text{ ohm}$$

The total resistance of the circuit, which we will represent by R, will be equal to

$$\begin{aligned} R &= .3 + 1.0 + 3.0 + .2 \\ &= 4.5 \text{ ohms} \end{aligned}$$

The effective pressure acting in the circuit, which we will represent by E, will be equal to the combined pressure of the six cells, since they all tend to produce a current in the same direction through the circuit, or

$$\begin{aligned} E &= 6 \times 1.5 \\ &= 9 \text{ volts} \end{aligned}$$

Substituting these values of resistance and pressure in equation (a) under Ohm's law gives

$$\begin{aligned} I &= \frac{9}{4.5} \\ &= 2 \text{ amperes} \end{aligned}$$

If two of the cells in the above problem were connected so that their pressures opposed the pressure of the remaining four, then the effective pressure would be obtained as follows:

$$\begin{aligned} E &= (4 \times 1.5) - (2 \times 1.5) \\ &= 6 - 3 \\ &= 3 \text{ volts} \end{aligned}$$

Parallel or Divided Circuits.—A parallel, or divided, circuit is one in which there are two or more paths provided for the current. For example, the three resistances R_1, R_2, and R_3, Figure 3, are connected in parallel between the terminals of the two dry cells. There are three paths for the total current, and the currents in the different paths will be to each other inversely as the resistances of the different paths. That is, if one path is twice the resistance of

another, it will carry only one-half as much current as the other path.

The reciprocal of a resistance; that is, one divided by the resistance, is called its *conductance*. Representing the combined resistance of a number of re-

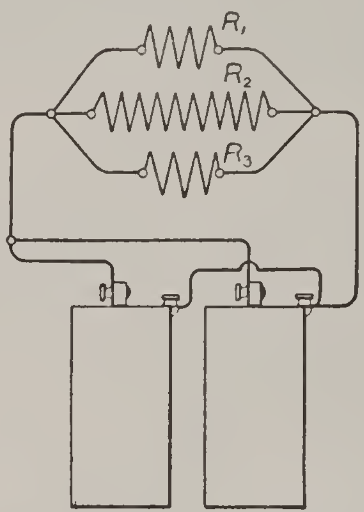


Figure 3.—Parallel Electrical Circuit.

sistances in parallel by R, then the conductance will be equal to $(1 \div R)$. The total conductance of a parallel circuit is equal to the sum of the conductances of the several parts,

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

The two dry cells in Figure 3 are connected in parallel, and the pressure of the combination is the same as that of a single cell, assuming their pressures and internal resistance are equal.

Example.—The three resistance R_1, R_2, and R_3, Figure 3, are 10, 4, and 20 ohms, respectively. Each dry cell has an electromotive force of 1.3 volts and an internal resistance of .1 ohm. Determine the total current produced by the two cells, the

current in each cell, also the current in each of the three resistances.

Solution.—Substituting in the above equation for the combined conductances gives

$$\frac{1}{R}=\frac{1}{10}+\frac{1}{4}+\frac{1}{20}=\frac{8}{20}=\frac{4}{5}$$

since

$$\frac{1}{R}=\frac{4}{5}$$

then

$$R=\frac{5}{4}=1\frac{1}{4}$$

$$=1.25 \text{ ohms}$$

The total internal resistance of the two cells in parallel is calculated in a manner similar to the above, or, representing the total internal resistance by r, we have

$$\frac{1}{r}=\frac{1}{\frac{1}{10}}+\frac{1}{\frac{1}{10}}$$

$$=20$$

or

$$r=\frac{1}{20}$$

$$=.05 \text{ ohm}$$

The total resistance of the entire circuit is equal to

$$1.25+.05=1.3 \text{ ohms}$$

Since the effective pressure is 1.3 volts, we obtain the total current by substituting in equation (a) under Ohm's law, which gives

$$I-\frac{1.3}{1.3}$$

$$=1 \text{ ampere}$$

This total current divides equally between the two dry cells, since their electromotive forces and internal resistances are equal in value or there will be a current of one-half ampere in each cell.

The currents in the 4-, 10-, and 20-ohm resistances will be to each other as 20, 8 and 4, or as 5, 2, and 1 are to each other. The 4-ohm coil will carry five-eighths of the total current; the 10-ohm coil, two-eighths; and the 20-ohm coil, one-eighth.

Electrical Work or Energy.—Work is the result of a force acting through a certain distance. For example, if a force of 100 pounds is required to raise a body through a vertical distance of 10 feet, there will be 100×10, or 1000 foot-pounds of work done. A force may exist without doing work; as, for example, you may shove against a wall with a certain force, yet you will do no work unless there is a movement of the wall. Thus, a generator may be operating and generating an electrical force, but it is not sufficient to overcome the resistance between the terminals of the machine, therefore, no current is produced and the generator is not doing any work. If, however, a conductor be connected to the terminals of the generator, a current will be produced by the electrical force and, as a result, the generator will do work. The electrical work done by the generator in producing the current will manifest itself as heat and cause the conductor to become heated.

Energy, in general, is the capacity or ability to do work and it is measured in the same unit as work, since it is numerically equal to the work done. Thus the energy possessed by a certain quantity of electricity at a certain electrical level, with respect to its energy at some other electrical level, is equal to the work done on or by the quantity in moving from

the first to the second electrical level. If the electricity moves from a higher to a lower level, it gives up energy or does work; while, if it moves from a lower to a higher level, work is performed and the energy possessed by the electricity is increased.

The unit of electrical work or energy is called the *joule*, and it is numerically equal to the work done in raising one coulomb of electricity through a difference in electrical level of one volt. The value of the work done in performing a given operation is independent of the time required. For example, it will require the same amount of work to raise a certain weight a given height in 10 minutes as would be required to raise it the same height in 1 hour. The electrical work W done in moving a certain quantity of electricity Q through a difference in electrical level of E volts may be determined by the following equation:

$$W = E \times Q$$

The quantity of electricity Q is equal to the product of the steady current in amperes times the time in seconds; and the work, in joules, done in a given time may be determined by the following equation:

$$\text{joules} = \text{volts} \times \text{amperes} \times \text{time (in seconds)}$$

$$W = E \times I \times t$$

Mechanical and Electrical Power.—Power is numerically equal to the rate of doing work, or the rate at which energy is expended. If mechanical work is being performed by a machine, such as a motor, at the rate of 33,000 foot-pounds per minute, or 550 foot-pounds per second, the machine is said to be developing 1 horsepower. The horsepower of a

machine, hp., may be determined by the following equation:

$$\text{horsepower} = \frac{\text{work in foot-pounds}}{33{,}000 \times \text{time (in minutes)}}$$

or

$$\text{hp.} = \frac{W}{33{,}000 \times \text{time (in minutes)}}$$

If the time is expressed in seconds in the above equation, then the constant 33,000 should be changed to 550. When electrical work is being done at the rate of one joule each second, the power developed is called a *watt*.

$$\text{Power (in watts)} = \frac{\text{joules}}{\text{time (in seconds)}}$$

$$P = \frac{\text{volts} \times \text{amperes} \times \text{time}}{\text{time}}$$

$$P = \text{volts} \times \text{amperes}$$

$$P = E \times I \text{ watts}$$

One watt is equal to .7373 foot-pounds per second, or one foot-pound per minute is equal to 1.356 watts. Since one horsepower is equal to 550 foot-pounds per second, an electrical equivalent rate of doing work would be

$$550 \div .7373 = 746 \text{ watts}$$
$$= 1 \text{ electrical horsepower}$$

Hence, to change mechanical horsepower to electrical units, multiply by 746, or

$$\text{watts} = \text{horsepower} \times 746$$

To change power in watts to horsepower, divide by 746, or

$$\text{horsepower} = \text{watts} \div 746$$

From the above discussion, it is readily seen that the electrical work or energy in joules is equal to the product of the power in watts times the time in seconds. The joule, however, is too small a unit for the majority of practical purposes, and, for this reason, larger units are generally employed. These larger units are merely a combination of a power and time unit as given below.

$$\text{watt-hours} = \text{watts} \times \text{hours}$$

$$\text{kilowatt-hours} = \text{kilowatts} \times \text{hours}$$

The kilowatt is equal to 1000 watts. The watt-hour meters used by the central station and power companies usually record the energy supplied to the consumer for lighting or power purposes in watt-hours or kilowatt-hours. Quite frequently the dials of these meters are not direct reading and their indication must be multiplied by a definite constant or factor, usually marked on the meter, in order to obtain the true value of the energy.

Example.—A 110-volt direct-current motor is operating under such a load that it draws 75 amperes from the 110-volt circuit to which it is connected. Determine the power input to this motor in watts, kilowatts, and horsepower; also the cost of energy to operate it for 10 hours if you have to pay 4 cents per kilowatt-hour for the energy.

Solution.—The power input to the motor in watts will be equal to the product of current and voltage, or

$$\begin{aligned} P &= 75 \times 110 \\ &= 8250 \text{ watts} \end{aligned}$$

Dividing the input in watts by 1000 gives input in kilowatts, or

$$P = 8250 \div 1000$$
$$= 8.25 \text{ kilowatts}$$

To change the input in watts to horsepower, divide by 746, which is the number of watts in 1 horsepower.

$$P = 8250 \div 746$$
$$= 11.06 \text{ horsepower}$$

The total energy input to the motor in kilowatt-hours for a period of 10 hours will be equal to the product of the power in kilowatts and the time in hours, or

$$8.25 \times 10 = 82.5 \text{ kilowatt-hours}$$

The cost of this energy at .04 dollar per kilowatt-hour will be

$$82.5 \times .04 = 3.30 \text{ dollars}$$

CHAPTER II

MAGNETISM, ELECTROMAGNETISM, MAGNETIC CIRCUIT, AND ELECTROMAGNETIC INDUCTION

Magnetism and the Magnet.—Any body which, when freely suspended or supported, assumes an approximately north and south position is called a *magnet,* and the property of the body causing it to assume this position is called *magnetism.* A natural magnet is a body possessing magnetic properties as found in nature; while an artificial magnet is a body possessing magnetic properties after some special treatment, such as placing it in contact with or under the influence of a natural or artificial magnet, or under the magnetizing influence of an electric current.

Any substance which is attracted by a magnet is called a *magnetic substance.* The most common magnetic substances are iron and steel, although cobalt and nickel are attracted to a slight extent by a strong magnet.

Magnetic Poles.—The end of a magnet which points approximately north, when the magnet is supported so that it is free to turn in a horizontal plane, is called the *north-seeking,* or *north-pole,* and is usually designated by *N.* The other end of the magnet is called the *south-seeking,* or *south pole,* and is usually designated by *S.*

If the like poles of two magnets be presented to

each other, it will be observed that there is a force of repulsion between them; while, if the unlike poles of two magnets be presented to each other, it will be observed that there is a force of attraction between them. The results just stated may be summarized in a general law, as follows: *Like magnetic poles repel each other,* and *unlike magnetic poles attract each other.*

Magnetic Field.—A magnetic field is any region where there will be a magnetic force acting on a magnetic substance if the substance be introduced into this region. All magnetic fields have two properties: direction and strength; and it is necessary to know both in order to completely define the field. If a bar magnet be placed directly under a piece of heavy writing paper and some fine iron filings sprinkled on the paper, at the same time slightly jarring it, the filings will arrange themselves in rather regular curves extending from one end of the magnet to the other. It will be observed, as you trace these curves from one end of the magnet, that they separate until you reach the center of the magnet, when they start to approach each other and continue to do so until you reach the other end. These curves in which the iron filings arrange themselves correspond in direction to what are called *lines of magnetic force.* The positive direction of these lines of force is taken as the direction in which the north pole of a compass needle will point when placed in the magnetic field. They all originate at the north pole of the magnet, pass through the surrounding space, and terminate at the south pole; and their direction at any point corresponds to the direction of the magnetic field at that point. The number of these imaginary lines of force which

pass through a unit of area perpendicular to their direction is a representation of the strength of the magnetic field. The total number of lines which are supposed to terminate at the magnetic pole will depend upon the total strength of the pole.

Magnetic Field Produced by a Current.—If a compass needle be placed beneath a conductor in which there is no current, the compass needle will come to rest in an approximately north and south position. The position of the compass needle will change, however, when a current is produced in the conductor, due to there being a magnetic field produced about the conductor by the current. The best results can be obtained by placing the compass needle and wire parallel to each other when there is no current in the conductor. The compass needle will come to rest in a position which corresponds to a combination of the magnetic field of the earth and that produced by the current in the conductor. If the current in the conductor be increased in value, the deflection of the compass needle from its original value will be increased. The direction in which the compass needle is deflected will change if the direction of the current in the conductor is changed. This simple experiment proves two things: *First,* the magnetic effect of the current depends upon the value of the current—it increases with an increase of current and decreases with a decrease of current; and *second,* the direction of the magnetic field produced by the current depends upon the direction of the current in the conductor.

Another method of investigating the direction of a magnetic field about a conductor is to place a conductor, in which a current may be produced, in a vertical position through a heavy piece of paste-

board or a thin wooden board, as shown in Figure 4, and then determine the direction of the magnetic field at various points about the conductor by means of a small compass needle. It will be found that the compass needle will point in one general direction around the conductor for a certain direction of current and in the opposite direction when the current is reversed in direction. Remembering that the positive direction of the magnetic field corresponds to the direction in which the north pole of the compass needle points, it will be observed that the direction of the

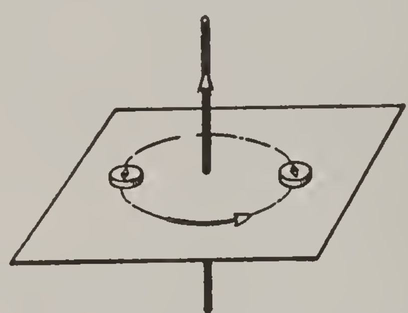


Figure 4.—Direction of the Magnetic Field about a Conductor in which there is a Current.

magnetic field is clockwise about the conductor as you look in the direction of the current, and counterclockwise as you look along the conductor in the opposite direction of the current. This simple relation is quite useful in determining the direction of current in a conductor, when the direction of the magnetic field is known, by means of the compass needle.

Another simple method of remembering the relation of the direction of current in a conductor and the direction of the magnetic field due to the current, which is known as the *right-hand rule,* is as follows: *Grasp the conductor with the right hand, the thumb being placed along the conductor and the fingers*

around the conductor, then the fingers will point around the conductor in the direction of the magnetic field when the thumb points in the direction of the current in the conductor.

Solenoid.—The magnetic effect of an electric current may be increased by bending the conductor carrying the current into a loop. The cross-section through a single turn of wire carrying a current and the magnetic field surrounding the turn are shown in Figure 5. The current is away from the

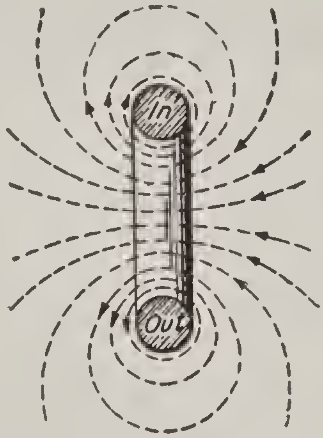


Figure 5.—Magnetic Field about a Coil of One Turn.

observer in the upper part of the wire and toward the observer in the lower part of the wire, which results in the direction of the magnetic field about the upper part being clockwise and about the lower part being counter-clockwise. It is apparent that the direction of the magnetic field due to the current in the different parts of the turn passes through the coil from the right side to the left, and each part of the turn acts with all the other parts on the center of the turn, thus making the magnetic field within the turn much stronger than the magnetic field outside the turn, which is indicated in the figure by drawing more lines of force per unit of area.

If the number of turns forming the coil be increased, the strength of the magnetic field inside the coil will be increased, since the greater part of the lines of force produced by each turn seem to pass around the entire winding instead of passing around

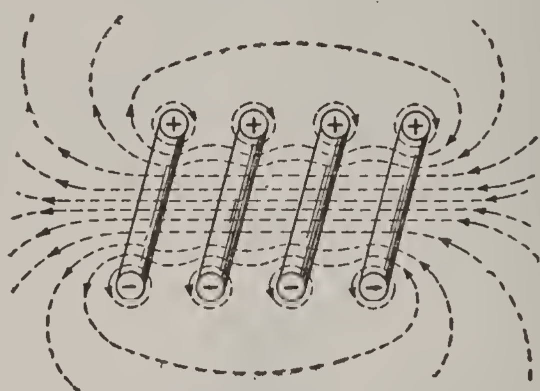


Figure 6.—Magnetic Field about a Coil of Several Turns.

the individual turns. A cross-section of a coil of several turns is shown in Figure 6, in which the majority of lines are shown passing through all the turns. A coil of this kind is called a *solenoid*.

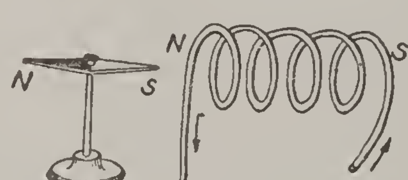


Figure 7.—Action of Solenoid on Compass Needle.

A solenoid, when there is a current in its winding, has all of the properties of a permanent magnet. The lines of force pass from the south pole to the north pole of the solenoid within the solenoid and from the north pole to the south pole outside the solenoid, just as in the case of a permanent magnet. The polarity of the solenoid may be determined by a compass needle, as shown in Figure 7, or it may

be determined by the following simple rule, if the direction of the current in the winding is known: *Grasp the solenoid with the right hand, placing the fingers around it in the direction of the current, the thumb will then point in the direction of the north pole,* as shown in Figure 8.

Magnetomotive Force.—The electric current in the winding of a solenoid sets up a force which drives the lines of magnetic force, called *magnetic flux,* through the path which they take, called the *magnetic circuit,* just as the generator in the electrical circuit produces an electromotive force which causes the elec-

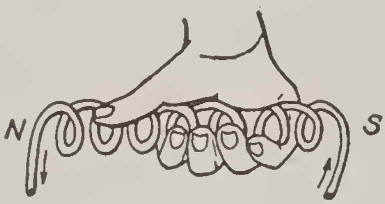


Figure 8.—How to Determine the Polarity of a Solenoid.

tricity to flow in the electrical circuit. This force due to the current is called the *magnetomotive force,* m.m.f. (abbreviated). The value of the magnetomotive force varies as the product of the number of turns in the solenoid and the current, in amperes, the turns are carrying. If we represent the number of turns by N and the current by I, the magnetomotive force in ampere-turns will be equal to NI. A magnetomotive force of a given value may be produced by any combination of current and turns such that their product is constant and equal to the required value of the magnetomotive force. For example, 1 ampere through 500 turns, 25 amperes through 20 turns, 50 amperes through 10 turns, etc., will all produce the same magnetomotive force.

The unit for magnetomotive force generally used in magnetic calculations is the *gilbert.* To change from ampere-turns to gilberts, it is necessary to multiply by $(4\pi \div 10)$, or 1.2566.

Reluctance.—The magnetomotive force acting on any magnetic circuit encounters a certain opposition to the production of a magnetic flux, just as the electrical pressure encounters a certain opposition, called *resistance,* in the electrical circuit to the production of a current of electricity. The opposition offered by the magnetic circuit to the production of the magnetic flux is called its *reluctance* and is usually represented by the symbol S. The reluctance of the magnetic circuit depends upon the kind of material composing the magnetic circuit and upon the dimensions of the circuit. It increases with an increase in length of the circuit; it decreases with an increase in area, all other conditions remaining constant; and it increases with a decrease in the value of a property of the material, called its *permeability* (which will be defined later) and represented by the symbol μ. The above relations may be written in the form of an equation as follows:

$$\text{reluctance} = \frac{\text{length of circuit in centimeters}}{\text{permeability} \times \text{area in square centimeters}}$$

$$S = \frac{l}{\mu \times A}$$

The unit in which reluctance is measured is called the *oersted.*

Reluctances are added in the same manner as resistances. If the magnetic circuit is composed of several different materials, as in the case of the motor,

the reluctance of each part must be computed and the results added, which will give the reluctance of the entire magnetic circuit.

Ohm's Law for the Magnetic Circuit.—Magnetomotive force, reluctance, and magnetic flux are related to each other just as electrical pressure, resistance, and current are related to each other. Magnetic flux is measured in a unit called the *maxwell;* it corresponds to one line of force and is represented by the symbol ϕ. The relation of the quantities associated with the magnetic circuit may be given in the form of an equation as follows:

$$\text{magnetic flux} = \frac{\text{magnetomotive force}}{\text{reluctance}}$$

$$\text{maxwells} = \frac{\text{gilberts}}{\text{oersteds}}$$

$$\phi = \frac{\text{m.m.f.}}{S}$$

$$\phi = \frac{1.2566\,NI}{\dfrac{l}{\mu A}}$$

$$\phi = \frac{1.2566\,NI\mu A}{l}$$

This last equation gives the value of the magnetic flux a current of I amperes will produce when carried about the magnetic circuit through N turns, the permeability of the material composing the circuit being represented by μ, its area in square centimeters by A, and its length in centimeters by l.

Field Intensity, Induction Density, and Permeability.—The number of lines of force in a magnetic field in air per unit of area perpendicular to the direction of the field corresponds to what is called the *magnetic field intensity,* or *field strength.* Field intensity, or field strength, is usually represented by the symbol H.

If a magnetic field can be produced within a solenoid, having no core, and a piece of magnetic material, such as iron, be introduced, the number of lines of force per unit of area will be greatly increased, although the current, or magnetomotive force, remains constant. The number of lines of force per unit area perpendicular to their direction in any material other than air corresponds to what is called *flux density,* or *induction density.* Induction density is usually represented by the symbol B.

The ratio of the number of lines per unit of area in air to those in some other material, the magnetomotive force being the same in both cases, is the permeability.

$$\text{permeability} = \frac{\text{induction density}}{\text{field strength}}$$

$$\mu = \frac{B}{H}$$

Magnetization Curves.—The permeability of iron is not constant but depends upon the degree to which it is magnetized. Hence, in order to compute the reluctance of a magnetic circuit, it is necessary to know either the field strength or the induction density and its relation to the permeability. A magnetization curve is a curve showing the relation between

the magnetizing force and the induction density for a given grade of material. The relation between induction density and the magnetizing force is different during the increase of magnetizing force from what it is during the decrease of magnetizing force. The tendency of the induction density to lag behind the magnetizing force is due to a property of the

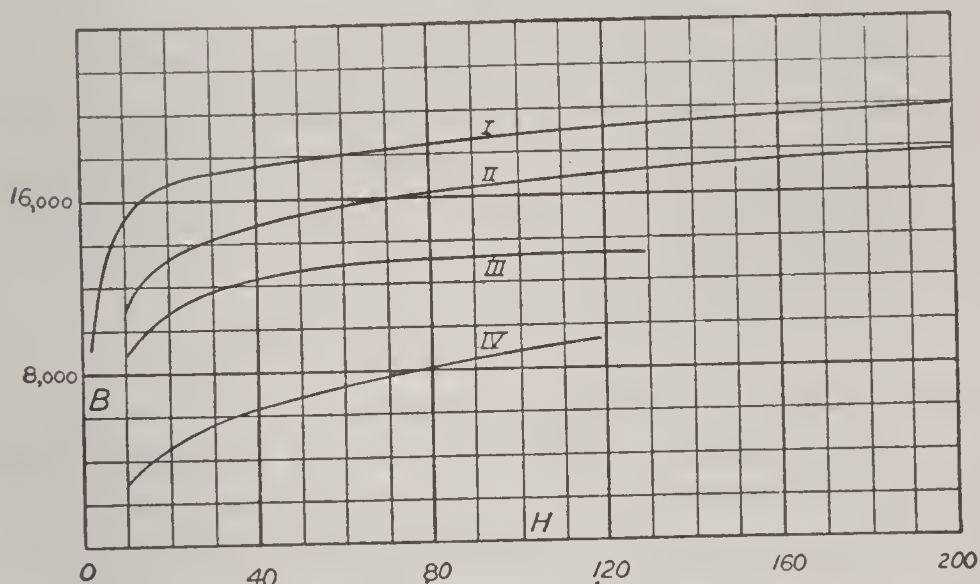


Figure 9.—Magnetization Curves. B—lines per square inch. H—ampere turns per inch. No. *I*.—Annealed sheet steel. No. *II*.—Cast steel. No. *III*.—Wrought iron. No. *IV*.—Cast iron.

material called *hysteresis* which is the cause of considerable loss in the operation of electrical machinery.

The magnetization curves for some of the more common materials are given in Figure 9. The induction density for the different field strengths are the average of the values obtained for an increasing and a decreasing field strength.

Hysteresis Loss.—When a piece of iron is magnetized by sending a current through a winding about it, there is a certain amount of energy stored in the magnetic field. If the current in the circuit be reduced to zero value, all of the energy used in magnet-

izing the piece of iron will not be returned to the circuit. This difference in the energy input and that returned will appear as heat, and it is called *hysteresis loss* since it is supposedly due to a lag of the magnetization behind the magnetizing force.

A piece of iron is carried through what is called a *magnetic cycle* when its magnetism is carried from a maximum value in one direction through zero to a maximum value in the opposite direction, again through zero, and back to the original value. When a piece of iron is carried through f magnetic cycles per second, the loss in power in watts is given by the following equation:

$$P_h = V \times K \times B^{1.6} \times f \times 10^{-7} \text{ watts}$$

In the above equation V represents the volume of the piece in cubic centimeters, K is a constant taking into account the kind of iron being tested, and B is the maximum value of the induction density in lines per square centimeter.

VALUE OF HYSTERETIC CONSTANT K FOR DIFFERENT MATERIALS

Ordinary Sheet Iron	.004
Thin Sheet Iron (good)	.003
Best Annealed Transformer Sheet Metal	.0015
Cast Steel	.012
Cast iron	.016
Forged Steel	.025

Electromagnetic Induction.—If a conductor and a magnetic field be moved relative to each other in such a manner that the conductor cuts across the

lines of force forming the field, there will be an induced electromotive force produced in the conductor. The direction of this induced electromotive force depends upon the relation between the direction of the magnetic field and the direction of the motion. If the fore finger, middle finger, and thumb of the right hand are placed at right angles to each other, and the fore finger is pointed in the direction of the magnetic field and the thumb in the direction of the motion, then the middle finger will point in the direction of the induced electromotive force.

The value of this induced electromotive force depends upon the rate at which the conductor is cutting the lines of force of the magnetic field. When the rate of cutting is uniform and at the rate of 100,000,000 each second, there will be an induced electromotive force of one volt in the conductor. The value of this induced electromotive force may be increased by connecting several conductors in series and moving them all across the magnetic field, as in the direct-current generator.

Inductance.—When a current is being established in a circuit, the lines of force surrounding the circuit and constituting the magnetic field are increasing in diameter. These lines of force are supposed to start as points at the center of the conductor and to move outward across the conductor as the field is increasing and to move inward across the conductor as the field is decreasing. This movement of the magnetic field with respect to the conductor results in there being an electromotive force induced in the conductor. The direction of this induced electromotive force will depend upon the direction of the relative movement of the magnetic field and conductor with respect to

each other. When the current in the conductor is increasing in value, the direction of the induced electromotive force will be in the opposite direction to the current, and it tends to prevent the current increasing. When the current is decreasing in value, the direction of the induced electromotive force will be in the same direction as the current, and it tends to maintain the current, or to prevent its decreasing. This property of the circuit which tends to prevent any change in the value of the current in the circuit is called its *self-inductance.* A circuit is said to have one unit of self-inductance, or one *henry,* when there is an electromotive force of one volt induced in the circuit, due to a uniform change in the current of one ampere each second.

When two electrical circuits are so related that a change in current in one will produce an electromotive force in the other, they are said to possess a *mutual inductance.* Two circuits are said to have one unit of mutual inductance, or one henry, with respect to each other when there is an electromotive force of one volt induced in one, due to a uniform change of current in the other of one ampere each second. A good example of the practical application of mutual inductance is found in the static transformer.

Eddy Currents.—When a mass of metal is moved in a magnetic field, currents, called *eddy currents,* will flow through the metal. These currents will heat the metal and represent a loss in the operation of dynamo-electric machinery.

The loss due to eddy currents is greatly reduced in electrical equipment by constructing the volume in which they occur of thin sheets of metal, called *laminations,* arranged in such a way that their planes

are perpendicular to the direction in which the eddy currents tend to flow. A good example of such construction is found in transformer and armature cores.

The eddy-current loss occurring in a given volume of iron may be calculated by means of the following equation:

$$P_e = V \times f^2 \times t^2 \times B^2 \times K$$

in which V is the volume of the iron in cubic centimeters; f is the frequency of the magnetic cycles per second; t is the thickness of the laminations in centimeters; B is the maximum induction density in lines per square centimeter; and K is a constant, depending upon the resistance of the iron per cubic centimeter, which is usually about 1.6×10^{-11}.

CHAPTER III

ALTERNATING-CURRENT ELECTRICAL CIRCUITS

Definition of Alternating Electromotive Force, or Current.—An alternating electromotive force, or current, is one that reverses in direction at certain regular intervals and at the same time it may be continuously changing in value. Such an electromotive force would be induced in a loop of wire if it were revolved in a magnetic field as shown in Figure 10.

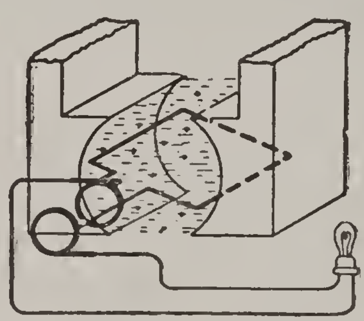


Figure 10.—Single Loop Revolving in a Magnetic Field.

This alternating electromotive force will produce an alternating current in the loop of wire if the ends be connected, or a current may be produced in an external circuit if the terminals of the loop be connected to the circuit by means of slip rings and brushes as shown in the figure. These slip rings are nothing more than two metal rings insulated from each other and connected to the terminals of the coil, one to each end. Two brushes bear upon the rings and thus provide a continuous connection between the coil and the external circuit.

The value of the electromotive force induced in the coil at any instant will depend upon the rapidity with which the sides of the coil are cutting across the lines of force of the magnetic field. It can be readily seen from an inspection of the figure that the sides of the coil are moving perpendicular to the direction of the magnetic field when the coil is in a horizontal position and, as a result, they are cutting the lines of force at the greatest rate. When the coil is in a vertical position, the sides are moving parallel to the direction of the magnetic field and they are cutting no lines of force. For intermediate positions the rate

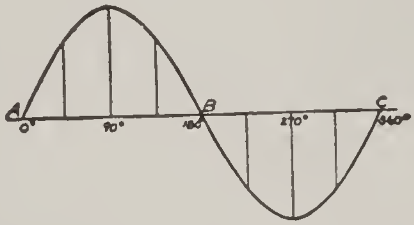


Figure 11.—Electromotive Force Induced in a Single Loop.

at which the lines will be cut will depend upon the sine of the angle between the position of the coil and a plane perpendicular to the direction of the magnetic field.

If we lay off a horizontal line and divide it into 8 equal divisions, and at each of these division points erect a perpendicular line whose length represents to a convenient scale the value of the electromotive force induced in the coil when it is in the angular position corresponding to that of the vertical line, we will have a curve similar to the one shown in Figure 11. The angular position of the coil should be measured with respect to a plane perpendicular to the direction of the magnetic field. As the coil rotates from this reference plane, the electromotive

will increase in value for the first 90 degrees, when it reaches its maximum value. It then decreases in value for the next 90 degrees and is zero at the end of 180 degrees, or one-half revolution. The values of the electromotive force are repeated for the remaining half revolution but in the opposite direction, since the motion of the sides of the coil with respect to the field is reversed. This is represented in the figure by drawing one-half of the curve below and one-half above the horizontal line.

Cycle, Frequency, Alternation, Period, Synchronism, and Phase Displacement.—When an alternating electromotive force, or current, has passed through a complete set of positive and negative values, starting at any value and again returning to that value in the same direction, it has completed what is called a *cycle*. A complete set of positive and negative values, or one cycle, is shown by the curve in Figure 11.

The number of cycles the electromotive force, or current, passes through in one second is called the *frequency*. Thus, a 60-cycle electromotive force, or current, would be one that passed through a complete set of positive and negative values 60 times per second.

An *alternation* is one-half of a cycle and corresponds to a complete set of positive or negative values of electromotive force, or current. The number of alternations in a given time is equal to twice the frequency, or a frequency of 60 cycles would mean 120 alternations per second.

The *period* of an electromotive force, or current, is the time in seconds required to complete one cycle. Thus the period of a 60-cycle electromotive force would be one-sixtieth of a second.

Two electromotive forces, or currents, are said to be *in synchronism* when they have the same frequency.

Electromotive forces and currents are said to be *in phase* when they pass through corresponding values of their respective cycles at the same time. The two curves shown in Figure 12 do not pass through zero or their maximum points at the same time and, therefore, they are said to be *displaced in phase.*

Let us assume that curve E, Figure 12, represents the electromotive force acting on a circuit, and that curve I represents the current produced by this electromotive force. It will be seen by a careful inspection of the figure that curve I passes through zero value in the positive direction after the electromotive force curve E, or the current is lagging behind the electromotive force.

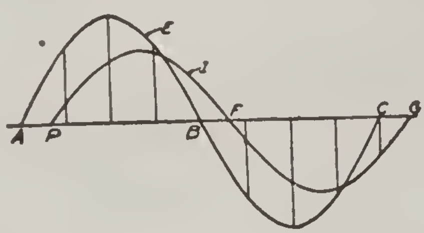


Figure 12.—Two Curves Displaced in Phase.

The phase displacement of two quantities with respect to each other is usually measured in degrees. The total length of the line AC, Figure 12, corresponds to 360 degrees, or one cycle of the electromotive; and likewise the length of the line DG, which is equal in length to AC, corresponds to one cycle of current. The two curves are displaced in phase from each other the same fractional part of 360 degrees as the length of the line AD is a part of AC. This displacement may be measured in time as well

as in degrees, but it is equal to such a fractional part of the period as the length of the line AD is a part of the line AC.

Maximum, Average, and Effective Values of Electromotive Force and Current.—The maximum value of an alternating electromotive force, or current, is the value of the electromotive force, or current, represented by the maximum ordinate of the electromotive force, or current, curve.

The average value of an alternating electromotive force, or current, is equal to the average of all of

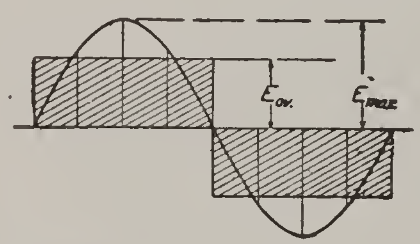


Figure 13.—Relation of Maximum and Average Values.

the instantaneous electromotive forces, or currents, for a complete alternation. The average value of a sine-wave electromotive force, or current, is equal to .636 of the maximum value, as shown in Figure 13.

The effective value of an alternating current is numerically equal to a steady direct current that will produce the same heating effect in a given time as is produced by the alternating current in a like time. Since the heating effect of a current varies as the square of the current, then the average heating effect of an alternating current will be proportional to the average value of the instantaneous currents squared; and the effective current will be equal to the square root of the average value of the instantaneous currents squared. The effective value of a sine-wave alter-

nating current is equal to .707 of the maximum value, as shown in Figure 14.

The effective value of an alternating electromotive force bears the same relation to its maximum value as exists between the effective and the maximum values of the currents, namely, the effective electromotive force is equal to .707 times the maximum.

Alternating-current ammeters and voltmeters indicate the effective values of current and electrical pressure.

The form factor of a wave representing the value of a current or electromotive force is numerically equal

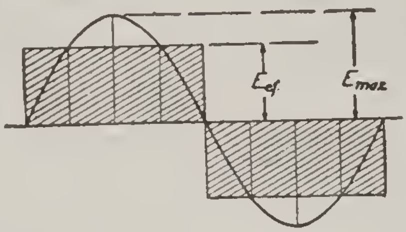


Figure 14.—Relation of Maximum and Effective Values.

to the effective value divided by the average value. For a sine wave it is 1.11. In the following calculations the current and electromotive force are assumed to follow a sine curve.

Ohm's Law for the Alternating-Current Circuit.—When an alternating electrical pressure acts upon a closed circuit, the effective current produced is equal to the effective pressure divided by the resistance of the circuit, provided there is no capacity or inductance in the circuit. If capacity or inductance, or both, be present in the circuit, the total opposition offered by the circuit to the flow of electricity through it will be greater than the ohmic resistance of the circuit unless the effects of capacity and inductance

neutralize each other, as will be explained later, in which case the opposition offered is equal to the ohmic resistance of the circuit. The combined effects of resistance, inductance, and capacity in opposing the free flow of electricity through a circuit is called the *impedance* of the circuit. The combined effects of the capacity and inductance is called the *reactance* of the circuit; the effect of capacity is called *capacity reactance;* and the effect of inductance is called *inductive reactance.* Reactance and impedance are both measured in ohms. The symbol generally used for impedance is Z, and that for reactance X, it being given a subscript C when it represents capacity reactance and a subscript L when it represents inductive reactance.

Ohm's law for the alternating-current circuit may be written as follows:

$$\text{effective current} = \frac{\text{effective pressure}}{\text{impedance}}$$

$$\text{amperes} = \frac{\text{volts}}{\text{ohms}}$$

$$I = \frac{E}{Z}$$

Effect of Inductance in an Alternating-Current Circuit.—The action of inductance in an alternating-current circuit is to cause the current to lag the electrical pressure, and, if the circuit contains inductance alone, the current and the electrical pressure will be displaced in phase from each other by 90 degrees.

The pressure required to produce a current of I

amperes in an inductance of L henries is given by the following equation:

$$E_L = 6.2832 \times f \times L \times I$$

in which f represents the frequency of the current in cycles per second.

The inductive reactance X_L is given by the following equation:

$$X_L = 6.2832 \times f \times L \text{ ohms}$$

Effect of Capacity in an Alternating-Current Circuit.—Two electrical conductors which are separated by some insulator, such as air, rubber, glass, mica, etc., constitute what is called a *condenser.* The medium separating the two conductors is called the *dielectric.* The action of a condenser in an electrical circuit is very similar to the action of an elastic diaphragm, such as rubber, stretched across a pipe upon which there is an alternating pressure acting. The action of capacity in an alternating-current circuit is to cause the current to lead the electrical pressure, and, if the circuit contains capacity alone, the current and the electrical pressure will be displaced in phase by 90 degrees.

The pressure required to produce a current of I amperes in a capacity of C farads is given by the following equation:

$$E_C = \frac{I}{6.2832 \times f \times C}$$

The capacity reactance X_C is given by the following equation:

$$X_C = \frac{1}{6.2832 \times f \times C}$$

Combined Effects of Resistance, Inductance, and Capacity in an Alternating-Current Circuit.—The resistance of an alternating-current circuit simply opposes the free flow of electricity through it without producing any phase displacement of the current and the electrical pressure.

The current required to produce a pressure of I amperes through a resistance of R ohms is given by the following equation:

$$E_R = R \times I$$

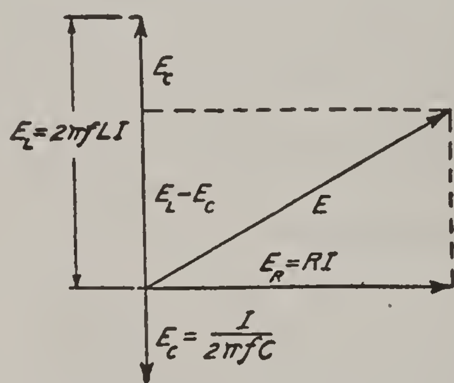


Figure 15.—Diagram of Pressures.

The three pressures E_R, E_L, and E_C may be represented as shown in the diagram in Figure 15. Since E_C and E_L are exactly opposite, one may be subtracted from the other as indicated in the figure in order to determine the resultant. This resultant is at right angles to E_R and it must be combined with E_R in order to get the value of E which is the resultant of all three pressures.

$$E = \sqrt{E_R^2 + (E_L - E_C)^2}$$

or

$$E = \sqrt{(RI)^2 + \left(6.2832 \times f \times L \times I - \frac{I}{6.2832 \times f \times C}\right)^2}$$

By taking I from under the radical sign, this equation may be written as follows:

$$E = I\sqrt{R^2 + \left(6.2832 \times f \times L - \frac{1}{6.2832 \times f \times C}\right)^2}$$

or

$$I = \frac{E}{\sqrt{R^2 + \left(6.2832 \times f \times L - \frac{1}{6.2832 \times f \times C}\right)^2}}$$

The above equation gives the value of the effective current I, in amperes, in terms of the impressed effective electrical pressure E, in volts; of the resistance R, in ohms; of the inductance L, in henries; of the capacity C, in farads; and of the frequency f, in cycles per second.

Series Alternating-Current Circuit.—In a series alternating-current circuit, the current is the same in all parts of the circuit just as in the series direct-current circuit. The sum of the electrical pressures over the various parts of a series circuit is not necessarily equal to the total pressure acting on the circuit when it is carrying an alternating current, unless the phase relation of the current in the circuit and the pressure over the various parts are the same. In general, the total pressure acting on the series circuit, when it is carrying an alternating current, is equal to the vector sum of the pressures over the different parts.

A series circuit composed of a resistance R, an inductance L, and a capacity C, is shown diagram-

matically in Figure 16. The total pressure may be determined as indicated in Figure 15.

Divided Alternating-Current Circuit.—The sum of the currents in the several branches of a divided circuit is equal to the total current, when the circuit is carrying a direct current. If the circuit is carrying an alternating current, the sum of the currents in the different branches will not be equal to the total current unless the phase relation of the current in the different branches and the electrical pressure acting on the divided portion are the same for each branch.

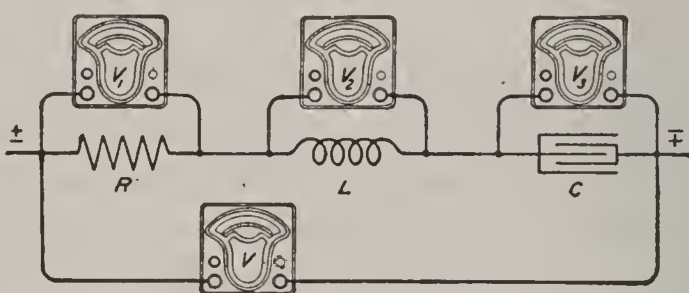


Figure 16.—Series Circuit.

In general, the total current in a divided circuit is equal to the vector sum of the various branch currents. The vector sum of the two currents is determined in the same manner as the resultant of two forces would be determined. If the two forces are in the same direction, the resultant is equal to their sum; if they are in opposite directions, the resultant is equal to their difference; if they are at right angles to each other, the resultant is equal to the square root of the sum of the squares of the two forces, etc.

Instantaneous Power in an Alternating-Current Circuit.—The instantaneous power in an alternating-current circuit at any instant is equal to the product of the current in the circuit at that instant and the

electrical pressure acting on the circuit at that instant. The two curves E and I, Figure 17, represent the pressure acting on a circuit and the current in the circuit, both being drawn to a suitable scale. A third curve may be drawn having ordinates propor-

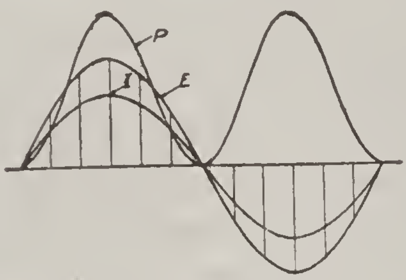


Figure 17.—Instantaneous Power, Current and Pressure in Phase.

tional to the product of the quantities represented by the curves E and I, as indicated by P, in the figure.

If the current and the electrical pressure be displaced in phase, as shown in Figure 18, the ordinates

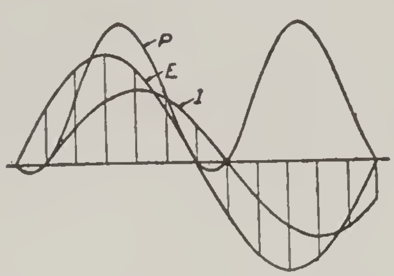


Figure 18.—Instantaneous Power, Current and Pressure out of Phase.

of the two curves do not change in sign at the same time and, as a result, the product of the quantities represented by these ordinates is not positive throughout the cycle, but is negative in sign for a portion of the time, which results in a portion of the curve P being below the horizontal line.

When the current and the pressure are in phase, or there is no resultant reactance, the power is all positive; that is, no power is being returned from the circuit to the generator. The power in such a case is proportional to the combined area of the loops in the power curve.

If the current and the pressure are not in phase, or the resultant reactance in the circuit is not zero, the effective power is proportional to the difference in the areas of the positive and the negative loops of the power curve, because the negative loops of the power curve represent power which is being returned from the line to the generator.

True Power in Alternating-Current Circuit.—The true power in an alternating-current circuit, in watts, in which the current and the pressure are in phase, is equal to the product of the effective values of the current and the pressure. The true power in an alternating-current circuit in which the current and the electrical pressure are displaced in phase by 90 degrees is zero, because the area of the positive and the negative loops of the power curve are the same and just as much power is returned to the generator as the generator delivers to the circuit. This condition is impossible in practice, as all circuits contain some resistance and, as a result, the current and the pressure can never be displaced in phase by 90 degrees.

The current and pressure are usually displaced in phase from each other, and the amount of this displacement depends upon the relation between the resultant reactance and the resistance of the circuit. The current, for convenience, may be thought of as composed of two parts: one in phase with the elec-

trical pressure, and the other at right angles to the electrical pressures. From the previous discussion, it is obvious that there is no resultant power due to the part of the current at right angles to the pressure, as the positive and the negative power loops are equal in area. The power due to the part of the current in phase with the pressure is all positive, or, if it was the only current in the circuit, the generator would be delivering power all the time. In order to calculate the true power in an alternating-current circuit, it is necessary to determine the value of the part of the current in phase with the pressure, and then multiply the effective value of this part of the current by the effective pressure.

The part of the current in phase with the pressure is equal to the total current I multiplied by the cosine of the angle between the current and the pressure. The true power, then, is equal to

$$P = E \times I \times \cos\theta$$

The product of E and I in the above equation is called the *apparent power;* and the quantity $\cos\theta$ is called the *power factor,* because it is the factor by which the apparent power must be multiplied in order to obtain the true or effective power. If the current and the pressure are in phase, the angle between them is zero and the cosine of θ is equal to unity, which results in

$$P = E \times I \times 1 = E \times I$$

Single-, Two-, and Three-Phase Circuits.—A single loop of wire revolving in a magnetic field, as shown in Figure 10, corresponds to what is called a *single-phase* alternating-current generator.

If a second loop of wire be mounted on the shaft with the first in such a position that the planes of the coils are at right angles to each other, the electromotive forces in the two loops will be displaced in phase by 90 degrees, and the combination corresponds to what is called a *two-phase* circuit. Each loop may be provided with two slip rings and be connected to independent circuits, or one ring may be common to both loops, in which case only three rings and three brushes are required, as shown in Figures 19 and 20.

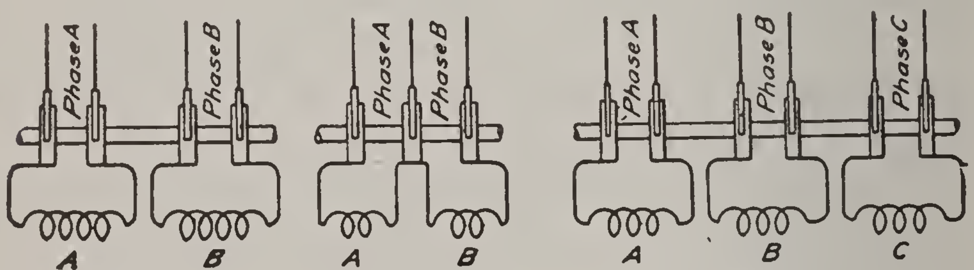


Fig. 19. Fig. 20. Fig. 21.

Figure 19.—Four-Ring Two-Phase Alternator. Figure 20.—Three-Ring Two-Phase Alternator. Figure 21.—Six-Ring Three-Phase Alternator.

If three loops of wire, whose planes are 60 degrees apart, be revolved in a magnetic field, there will be electromotive forces induced in the loops which will be displaced in phase from each other by 120 degrees. Each of these loops may be provided with two slip rings and two brushes and such be connected to independent circuits, as shown in Figure 21, or three loops may be interconnected and only three rings and three brushes will be needed. Two possible methods of connecting the three loops are shown in Figures 22 and 23. The loops are said to be *delta-connected* in Figure 22, and *star-connected* in Figure 23. The delta connection is usually represented by the symbol Δ, and the star connection by the letter Y.

The following relations hold for the voltage and the current relations for the two connections, when the loads are balanced. The voltage between lines in the delta connection is equal to the voltage in each

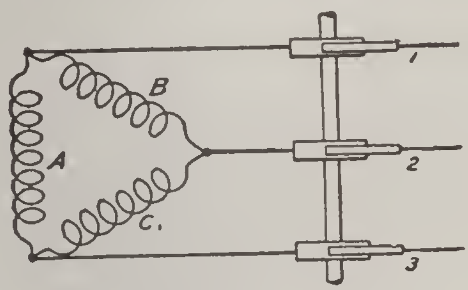


Fig. 22.

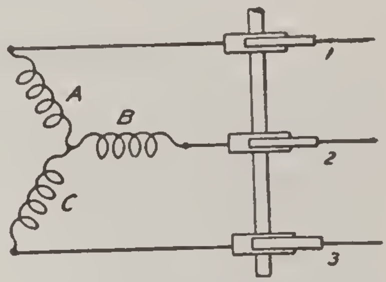


Fig. 23.

Figure 22.—Delta-Connected Three-Phase Alternator. Figure 23. —Star-Connected Three-Phase Alternator.

loop, and the current in each outside line is equal to the $\sqrt{3}$ times the current in each loop. In the star connection, the current in the different lines is equal to the current in the loop connected to that line, and the voltage between lines is equal to the $\sqrt{3}$ times the voltage in each loop.

CHAPTER IV

ELECTRICAL MEASUREMENTS

Measurement of Current.—The current in a circuit is measured by means of an instrument called an *ammeter.* The operation of the ammeter depends upon some effect of the current, such as the heating effect, magnetic effect, etc., and, since the magnitude of these various effects vary with the value of the current, it is possible to determine the value of the

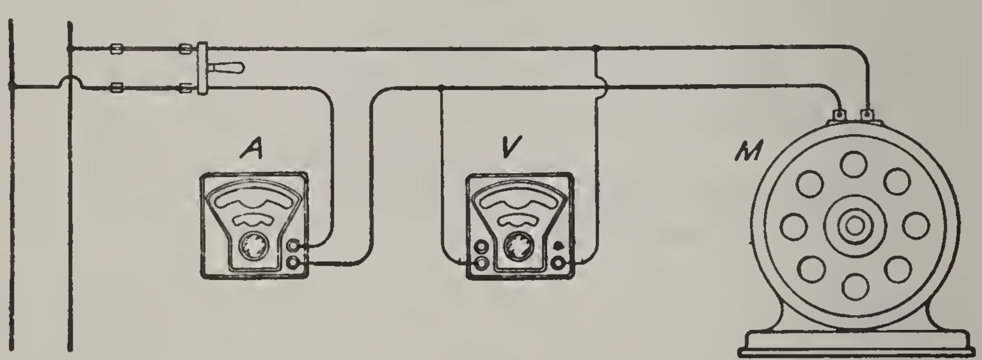


Figure 24.—Proper Connection of Ammeter and Voltmeter.

current by determining the magnitude of the effect. The scales of the ammeters, however, are usually marked to read directly in amperes, or current, instead of indicating the value of the effect of the current.

Ammeters are always connected directly in series with the circuit in which it is desired to measure the current, as indicated in Figure 24, which shows an ammeter *A* connected directly in one of the lines lead-

ing to the motor M. This ammeter will indicate the total current supplied to the motor.

The resistance of an ammeter should be very small in order that the power required to operate it be small.

An ammeter shunt is a resistance of low value which may be connected in parallel with an ammeter and thus increase the value of the current that it is possible to measure with the ammeter. When the resistance of the shunt bears a definite relation to the resistance of the ammeter, there will be a definite part of the total current in the ammeter circuit. For example, if the resistance of the ammeter circuit is four times the resistance of the shunt circuit, only one-fifth of the total current will pass through the ammeter and the value of this current as indicated by the ammeter must be multiplied by five in order to get the value of the total current. An ammeter shunt can be used in measuring direct current only, since the relation of the currents in the two branches of a divided circuit, when it is carrying alternating current, is not necessarily equal to the inverse relation between the resistances of the two branches.

When it is desired to measure an alternating current in excess of the current capacity of the ammeter, use is made of a device called a *current transformer*. The construction of the current transformer is such that the current in the secondary winding is a definite part of the current in the primary winding. A low-reading ammeter may be used to measure the current in the secondary winding, and this current multiplied by the ratio of primary to secondary currents will give the value of the current in the primary circuit or line, since the primary part of the trans-

former is in series with the line in which it is desired to measure the current. A switchboard type of current transformer is shown in Figure 25.

Measurement of Pressure.—The difference in electrical pressure between any two points on an electrical circuit may be determined by means of an instrument called a *voltmeter.* Voltmeters operate on the same general principles as ammeters; that is, their indication depends upon the value of the current passing through them. The value of the current in the voltmeter will depend upon the resistance of the voltmeter and the pressure to which it is connected and this current will vary directly as the pressure, if the resistance remains constant, which results in the voltmeter indication varying with the difference in pressure between its terminals. The proper method of connecting a voltmeter is shown in Figure 24. It is desirable to have the resistance of voltmeters as large as possible.

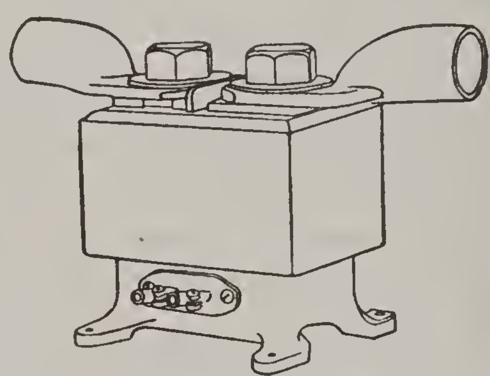


Figure 25.—Switchboard Type of Current Transformer.

The capacity of a direct-current voltmeter and of some alternating-current voltmeters may be increased by connecting a resistance, called a *multiplier,* in series with the voltmeter. For example, if a voltmeter has a resistance of 15 000 ohms and a resist-

ance of 60,000 ohms is connected in series with it, then the total pressure acting on the two in series will be equal to the voltmeter indication multiplied by five, since only one-fifth of the total pressure will be between the terminals of the voltmeter as its resistance is one-fifth of the total resistance.

A low-reading alternating-current voltmeter may be used in measuring high electrical pressures by means of a device called a *potential transformer.* The voltage between the terminals of the secondary winding may be measured by means of the voltmeter, and

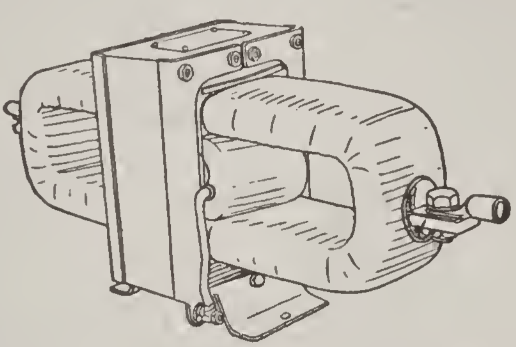


Figure 26.—Potential Transformer.

this reading multiplied by the ratio between the primary and the secondary voltages will give the value of the voltage between the terminals of the primary winding. A pressure, or potential, transformer is shown in Figure 26. When a potential transformer is used, the indicating instrument is entirely insulated from the high pressure, and there is very little likelihood of the instrument being injured or of the attendants getting in contact with the high-pressure circuit.

Drop in Potential Method of Measuring Resistance.—The value of a resistance may be determined by sending a current through it and measuring the difference in pressure between the terminals of the

resistance for a definite value of current. The scheme of connection is shown diagrammatically in Figure 27, in which R represents the resistance to be measured; A is an ammeter connected in series with the resistance; B is a battery to be used in sending a current through the resistance—any source of direct current may be used; Rh is a rheostat which may be used to control the value of the current; and V is a voltmeter for measuring the difference in pressure between the terminals of the resistance. If the cur-

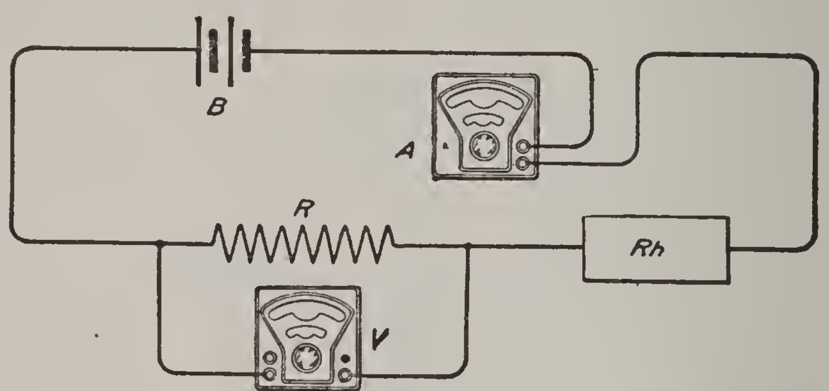


Figure 27.—Drop in Potential Method of Measuring Resistance.

rent through the voltmeter be neglected, then the ammeter will indicate the current through the resistance R, and the value of the resistance R is equal to the pressure in volts, as indicated by the voltmeter, divided by the current in amperes, as indicated by the ammeter A, or

$$R = \frac{E}{I}$$

When the resistance of the voltmeter circuit is large in comparison to the value of the resistance R, the current through the voltmeter is small in comparison to the current through the resistance R and may be neglected. In some cases the current through the volt-

meter cannot be neglected but must be subtracted from the value of the current as indicated by the ammeter in order to obtain the value of the current in the resistance being measured. The current in the voltmeter is equal to the value of the pressure as indicated by the voltmeter divided by the resistance of the voltmeter R_V, or

$$I_V = \frac{E}{R_V}$$

The current I_R through the resistance R, then, is

$$I_R = I - I_V$$

or

$$I_R = I - \frac{E}{R_V}$$

and the value of the unknown resistance will be

$$R = \frac{E}{I_R}$$

$$= \frac{E}{I\,R_V - E} \times R_V$$

This method of measuring resistance may be used in measuring the resistance of armatures, fields, etc.

Series-Voltmeter Method of Measuring Resistance.—The scheme of connections for measuring resistance by the series-voltmeter method is shown in Figure 28. A voltmeter V is connected in series with an electrical pressure produced by the direct-current generator G and the unknown resistance, which in this case is the resistance between an insulated wire and the metal

pipe, the circuit being completed through the ground. The electrical pressure produced by the generator will be distributed around the above circuit in proportion to the resistance of the different parts. The pressure between the voltmeter terminals, which will be indicated by the voltmeter, will bear the same relation to the pressure over the unknown resistance as the resistance of the voltmeter bears to the value of the unknown resistance. The pressure over the unknown resistance will be equal to the total pres-

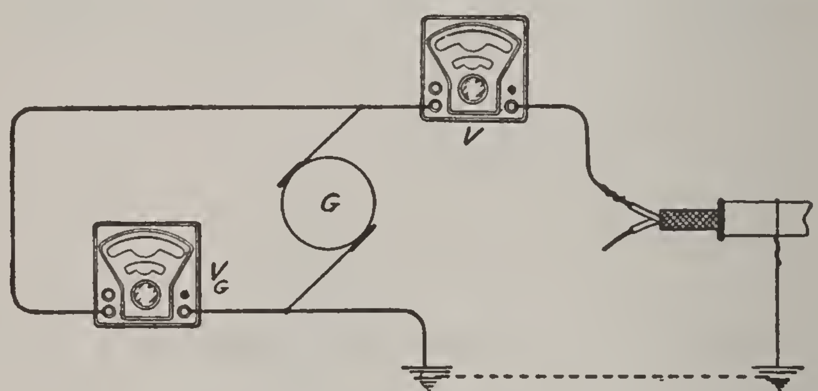


Figure 28.—Series-Voltmeter Method of Measuring Resistance.

sure produced by the generator minus the pressure over the voltmeter. The total pressure may be determined by connecting the voltmeter directly across the terminals of the machine, or, if the pressure is rather unsteady, it may be best to use a second voltmeter V_G. Representing the total pressure by E, the pressure between the terminals of the voltmeter by E_V, and the pressure over the unknown resistance by E_X, we have the following equation:

$$E_X = E - E_V$$

The current in the voltmeter and the unknown resistance will be the same and are equal to the pressure

E_V indicated by the voltmeter divided by the resistance of the voltmeter R_V, or

$$I = \frac{E_V}{R_V}$$

Now the value of the unknown resistance R_X is equal to the pressure between its terminals divided by the current it is carrying, or

$$R_X = \frac{E_X}{I}$$

$$= \frac{E - E_V}{E_V} \times R_V$$

Measurement of Resistance by Wheatstone Bridge. —The connections of the various elements of a simple Wheatstone bridge are shown diagrammatically in

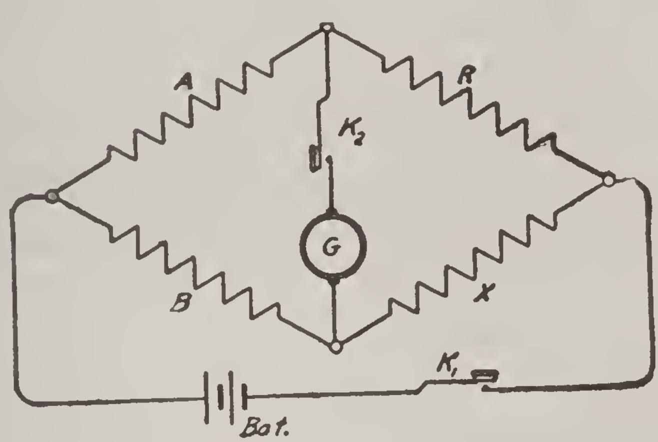


Figure 29.—Scheme of Wheatstone Bridge.

Figure 29. The resistances A and B are called the *ratio arms*, and they are usually composed of a number of resistances differing in value by multiples of 10, the lowest being perhaps .1 ohm and the largest 10,000 ohms. The resistance R is called the *rheostat* of the bridge; it is usually composed of a le...

ber of resistances ranging in value from .1 ohm to several thousand ohms. In commercial types of Wheatstone bridges, the various parts of these resistances may be connected in circuit, or not, by means of suitable switching devices. The resistance X corresponds to the unknown resistance whose value is to be determined. A galvanometer G and a battery are connected as indicated with keys K_2 and K_1 in circuit. When a balance of the bridge is obtained—that is, when there is no current through the galvanometer with both keys K_1 and K_2 closed, the ratio of the resistance X to the resistance R will be the same as the ratio of the resistance B to the resistance A, or

$$\frac{X}{R}=\frac{B}{A}$$

and

$$X=\frac{B}{A}R$$

If the resistances A and B are equal when a balance is obtained, then the resistances R and X will be equal. If the resistance A is ten times the resistance B, then the resistance R will be ten times the resistance X, or *vice versa.*

Commercial Wheatstone bridges assume a number of different forms, but they all operate on the same fundamental principle.

Voltmeter-Ammeter Method of Measuring Power.—The power in watts in a direct-current circuit is equal to the product of the current in amperes and the pressure in volts. In an alternating-current circuit, the product of the current in amperes and the pressure in volts gives the power only when the cur-

rent and the pressure are in phase. When they are not in phase, their product must be multiplied by a factor, called the *power factor,* in order to obtain the value of the true power.

The power taken by a motor may be measured by means of a voltmeter and an ammeter, as shown in Figure 24. In this case the ammeter A indicates the combined currents through the motor and voltmeter, but the voltmeter current is usually so small in comparison to the total current that it may be neglected without causing an appreciable error. This method cannot be relied upon for an alternating current, as the current and the pressure are out of phase in the majority of cases, and an instrument called a *wattmeter* must be used.

Indicating Wattmeter.—A wattmeter is an instrument for measuring power, and its indication depends upon the combined effects of the load current, or a definite part of it, in the circuit in which the power is being measured and of the pressure acting on the load. If the current and the pressure are in phase, the force acting on the moving system will remain constant in direction; while, if they are displaced in phase, the force acting on the moving system will reverse in direction, and the resultant deflection will be produced by an average force which will be proportional to the difference in the forces acting in the two directions. Such an instrument will indicate the true power regardless of the phase relation of the current and the pressure.

Power in a Two-Phase Circuit.—The total power in a two-phase four-wire or three-wire system is equal to the sum of the power in the separate phases. The power in each phase may be determined by connect-

ing the series coil of the wattmeter in circuit so as to measure the current in that phase and its pressure coil across the pressure of that phase.

A single wattmeter may be used in measuring the power in a three-wire two-phase system, balanced or unbalanced load, by connecting the series coil in the neutral or common wire and then take two readings: *first,* with the pressure coil connected between the neutral and one outside wire; and *second,* between the neutral and the other outside wire. If the connection of the pressure circuit to the common wire must be changed in order that the wattmeter read in the same direction in both cases, the difference of the two wattmeter readings represents the total power; while, if the two wattmeters read in the same direction without any change in the connection of the pressure circuit to the common wire, the sum of the two readings represents the total power.

Power in a Three-Phase Circuit.—The total power in a balanced three-phase three-wire system is equal to the product of the current in one of the lines, the pressure between lines, and the $\sqrt{3}$, or

$$P = \sqrt{3}\,EI \text{ watts}$$

The power in a balanced three-phase three-wire or four-wire system may be measured by a single wattmeter by connecting the series coil of the wattmeter in one of the main lines and the pressure coil across the pressure of the phase in which the current coil is connected. This wattmeter reading multiplied by three will give the total power. In a four-wire system, the pressure of any phase exists between the line of that phase and the neutral. In a three-wire sys-

tem, an artificial neutral will have to be established, which may be done by means of a Y box.

The total power in a three-phase three-wire or four-wire system may be measured by means of two wattmeters as follows: The series coils of the wattmeters are connected in two of the lines and the pressure coil of each of the wattmeters is connected between the line in which its series coil is connected and the line in which there is no series coil. If the power factor of the system is greater than one-half, the sum of the two wattmeter readings gives the total power; while, if the power factor is less than one-half, the difference of the two readings gives the total power. If the readings of both wattmeters increase in value as the load is increased, the power factor is greater than one-half, and, if the reading of one wattmeter increases and the other decreases as the load increases, the power factor is less than one-half.

Using Electrical Instruments.—Permanent connections should not be made until the operator is sure that the capacity of a meter will not be exceeded by the voltage or amperage. Cables attached to meters should not be altered as they form part of the instrument's resistance. If the meter is found to be sluggish, readings may be taken while tapping the case with the finger. Meters of any type generally give the best results when laid flat when in use, although portable types may be used in any position. Switchboard instruments are, of course, designed for a vertical position. Care is required if meters are to retain their accuracy.

CHAPTER V

ARMATURE WINDING FOR DIRECT-CURRENT MOTORS

Types of Armature Cores.—Armatures may be divided into three general classes, according to the shape of the cores and the manner in which the winding is placed upon the core. These classes are:

(a) Ring armatures
(b) Drum armatures
(c) Disk armatures

(a) The ring armature is one in which the core is in the shape of a ring, and the winding passes in and

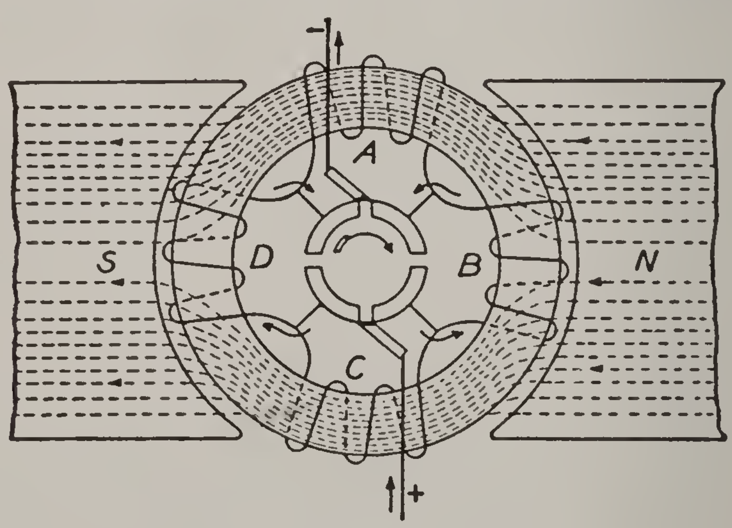


Figure 30.—Ring Armature.

out around the core as shown in Figure 30. The portion of the winding inside the ring cuts no lines of force and, as a result, does not help in producing the required electrical pressure, in the case of the generator, or the torque, in the case of the motor.

(b) In the drum armature, the amount of wire which is effective in producing the electrical pressure in the generator and the torque in the motor is a larger part of the total amount, since the wire is wound back and forth across the surface of the core, which is in the form of a drum.

(c) In the disk armature, the portion of the winding in which the electrical pressure is generated instead of being on the cylindrical surface, as in the case of the ring and drum types, is on the flat sides of a disk, and the poles are also placed on opposite sides of this disk instead of being placed around its outer edge. The drum armature is used almost entirely, as it does not require hand winding, and the coils can be wound and formed independent of the armature.

Types of Windings.—All of the armature windings for both direct- and alternating-current machines belong to one of two classes:

(a) Open-coil windings
(b) Closed-coil windings

(a) The open-coil winding is one in which, starting at one terminal of the winding and tracing through the winding, a "dead-end" is finally reached. Open-coil windings are at present used entirely on alternating-current machines.

(b) The closed-coil winding is one in which, starting at any point on the winding and tracing through the winding, the starting point will be reached after having passed through all, or some sub-multiple of, the conductors forming the winding.

Winding Element.—The element of an armature winding may be defined as that portion of a winding,

which, beginning at a commutator segment, ends at the next commutator segment encountered in tracing through the winding.

An element may consist of more than one turn, as shown in Figure 31, which represents three elements for different types of armature windings, and each element is composed of two turns. The number of turns in each element should be as small as possible, in order that its self-inductance be small, which results in better commutation than could occur if the elements had a high self-inductance.

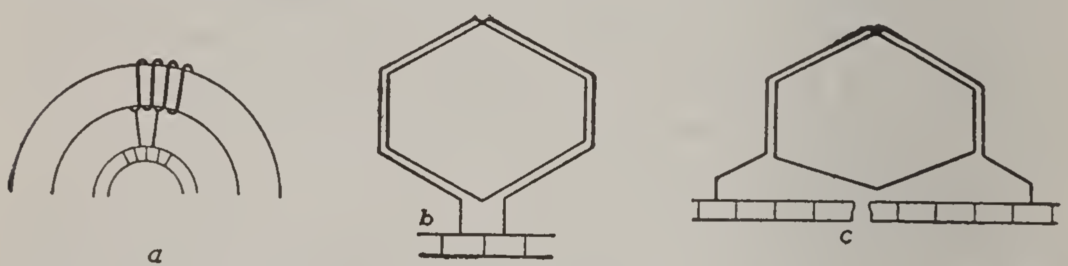


Figure 31.—Elements of an Armature Winding. *(a.)* Ring Winding. *(b.)* Lap Winding. *(c.)* Wave Winding.

The part of the winding in which the electromotive force is induced is called a *conductor*, and the number of conductors in any winding will be equal to the number of times the winding passes from one end to the other under the poles. In a ring winding, there is only one conductor per turn; while in the drum winding there are two conductors per turn.

Lap and Wave Windings.—The meaning of the terms lap and wave as used in defining a certain type of winding will be evident from an inspection of Figures 32 and 33. In Figure 32, the various elements lap back on each other, while in Figure 33 they progress continuously in a wave-fashion around the armature. Lap and wave windings are often called *parallel* and *series* windings, respectively.

Front and Back Winding Pitch, and Commutator Pitch.—In speaking of an armature, the commutator end is called the front of the armature and the other end is called the back of the armature. If all of the

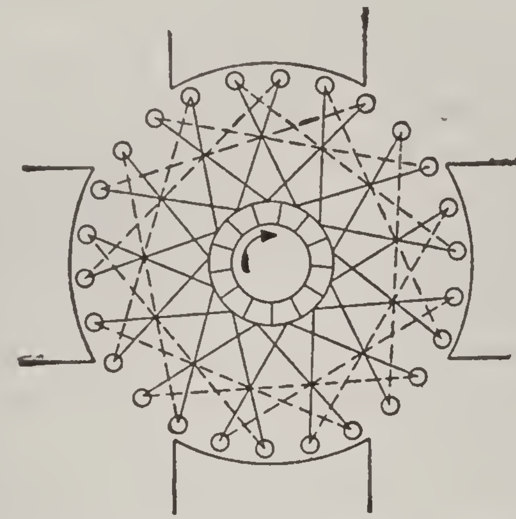


Figure 32.—Simplex Singly Re-entrant Lap Winding.

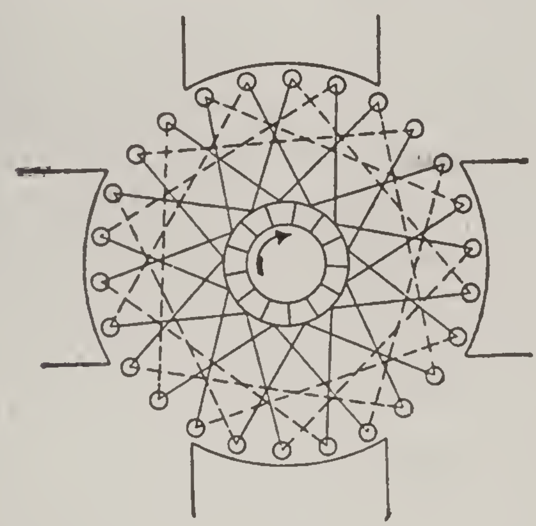


Figure 33.—Simplex Singly Re-entrant Wave Winding.

conductors forming the armature winding be numbered in regular order all the way around the armature, then the back pitch of the winding will be numerically equal to the difference in the numbers of the conductors connected together at the back

end of the armature. Likewise the front pitch will be equal to the difference in the numbers of the conductors connected together at the front end of the armature. In the lap winding, the front and back pitches are of opposite sign, because in tracing through the winding you pass around the armature core in opposite directions at the two ends. In the wave winding, the front and back pitches are of the same sign, because in tracing through the winding you pass around the armature core in the same direction at the two ends.

If the commutator segments be numbered consecutively around the commutator, then the commutator pitch will be equal to the difference in the numbers of the commutator segments connected directly to the terminals of any element.

Simplex and Multiplex Windings; Degree of Reentrancy.—If all of the conductors forming the armature winding be interconnected as shown in Figures 32, 33, 34, 35, 36, and 37, the winding is said to be singly re-entrant, because it closes on itself only once. If it were possible to remove a singly re-entrant armature winding from the armature core without disturbing any of the various electrical connections, there would be one large loop of wire formed with the commutator segments connected at regular intervals.

Figures 32 and 34 are two different methods of representing a lap winding, and Figures 33 and 35 are two different methods of representing a wave winding.

It will be observed that in tracing through an element of the winding shown in Figure 34 that the terminals of an element are connected to commutator

segments which are adjacent to each other, while in Figure 36 the terminals of an element are connected to commutator segments which are two removed from each other. A lap winding whose elements terminate at adjacent commutator segments is called a *simplex*

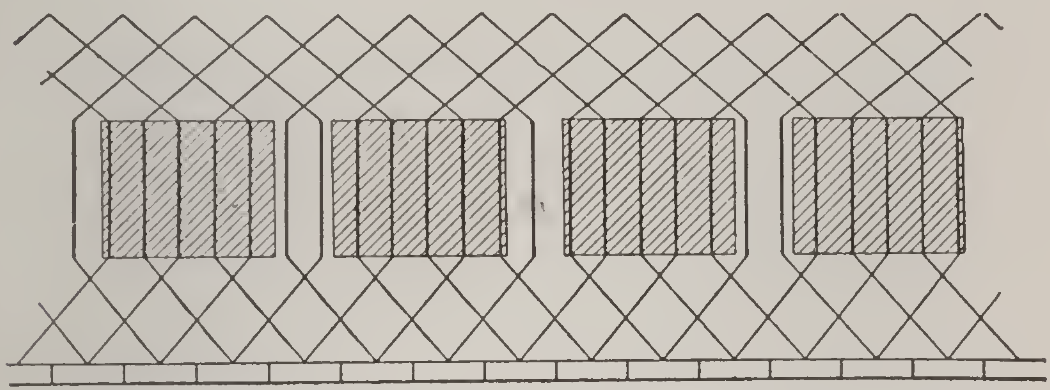


Figure 34.—Simplex Singly Re-entrant Lap Winding.

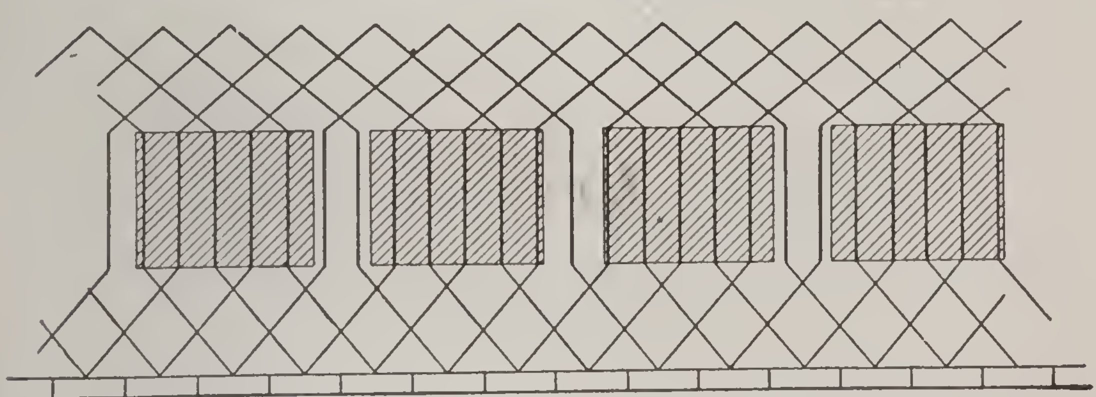


Figure 35.—Simplex Singly Re-entrant Wave Winding.

winding; one whose elements terminate at commutator segments separated by one segment is called a *duplex* winding; if the commutator segments are separated by two segments, it is called a *triplex* winding, etc.

You will observe that after you have traced through two elements of the winding shown in Figure 35, you arrive at a commutator segment one re-

moved from the one from which you started; while in Figure 37, after tracing through two elements of the winding, you arrive at a commutator segment two removed from the one from which you started. The wave winding shown in Figure 35 is called a

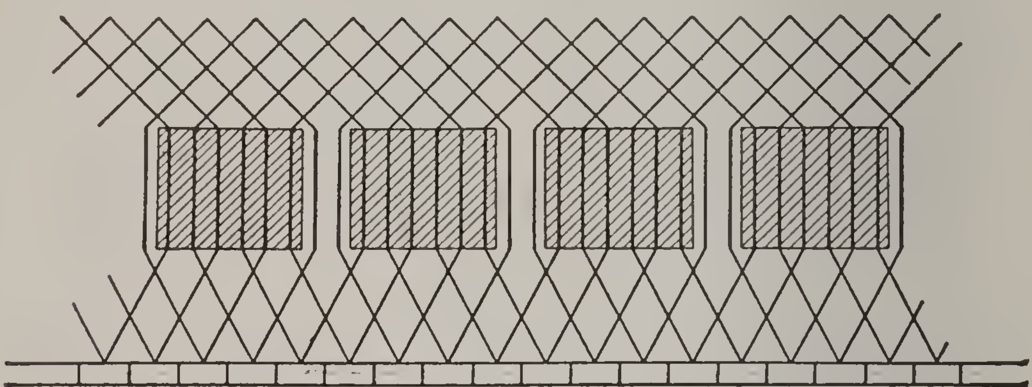


Figure 36.—Duplex Singly Re-entrant Lap Winding.

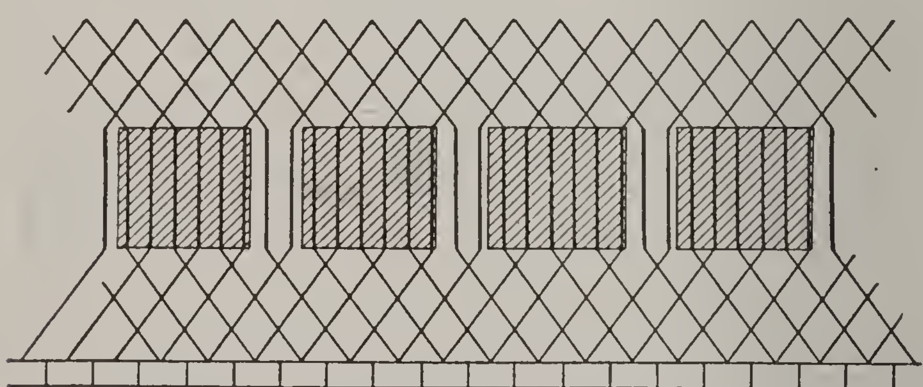


Figure 37.—Duplex Singly Re-entrant Wave Winding.

simplex winding, and the one shown in Figure 37 is called a *duplex* winding. In general, the multiplicity of a wave winding is equal to the difference in the numbers of the commutator segments forming the terminals of a number of elements, equal to one-half the poles, directly in series. Thus, if, after tracing through six elements of a wave winding for a twelve-pole machine, you arrive at a commutator seg-

ment three removed from the one from which you started, the winding is called a *triplex* winding.

An inspection of Figures 38 and 39 will disclose the fact that all of the various elements forming each of these two windings are not interconnected in a

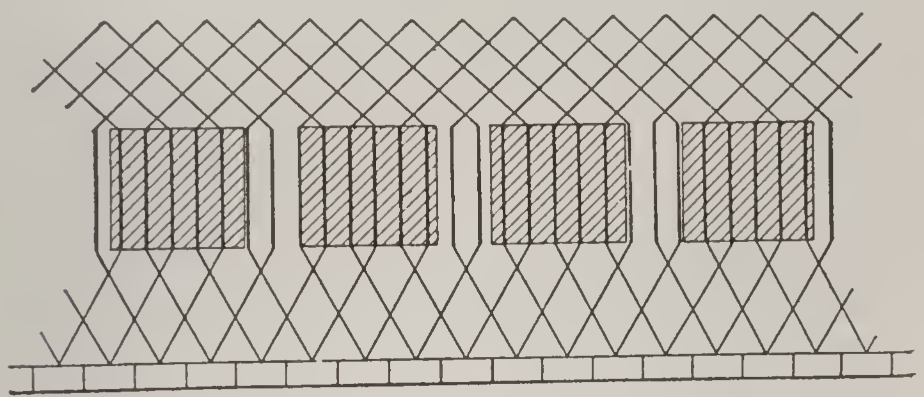


Figure 38.—Duplex Doubly Re-entrant Lap Winding.

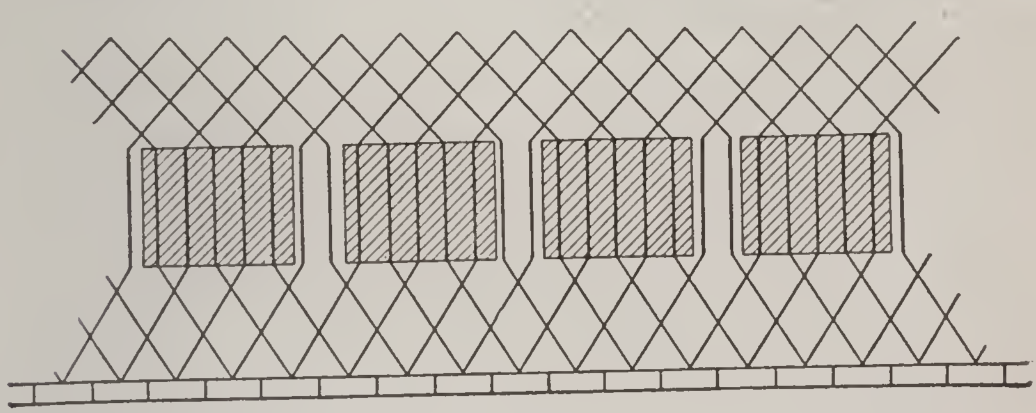


Figure 39.—Duplex Doubly Re-entrant Wave Winding.

single closed circuit, as has been the case in all of the windings thus far discussed. If the windings shown in Figures 38 and 39 were removed from the armature core without disturbing any of the electrical connections, two independent loops of wire would be formed in each case, and for this reason the windings are said to be doubly re-entrant, that is, each winding closes on itself twice.

Number of Brush Sets Required.—The number of brush sets required for the successful and satisfactory operation of a lap winding is equal to the number of poles. The machine will operate with a less number than this, but its current capacity will be reduced as the useful paths through the winding from terminal to terminal will be reduced.

Only two brush sets are required in the case of a wave winding. A number of brush sets equal to the number of poles is generally used, however, as commutation is usually better with the larger number of brushes. Armatures for street car motors are usually wave wound and, in the majority of cases, use only two brush sets.

Number of Paths through Armature Winding.—The number of paths between the positive and the negative terminals of an armature depends upon the type of winding and the number of poles the machine has. For a lap winding, the number of paths is equal to the multiplicity of the winding multiplied by the number of poles. For example, a simplex lap-wound armature for a ten-pole machine will have ten circuits from the positive to the negative brush ring, provided there are as many brush sets as poles. A triplex lap-wound armature for a ten-pole machine will have thirty circuits from the positive to the negative brush ring.

The number of circuits in a wave winding is equal to twice the multiplicity, regardless of the number of poles. For example, a triplex wave winding will have six circuits between the positive and the negative brush ring.

Electromotive Force Generated in Armature Winding.—The electromotive force generated in the arma-

ture winding of a machine depends upon the magnetic flux entering or leaving the armature at each pole, the number of poles, the number of armature conductors in series in each path through the armature winding, and the speed at which the armature is revolving. The number of conductors in series in each path is equal to the total number, which we will represent by the symbol Z, divided by the number of paths, which we will represent by the symbol a. All of these conductors in series cut the flux under all of the poles once in each revolution, or the total flux cut by each conductor is equal to the flux per pole, which we will represent by the symbol ϕ, multiplied by the number of poles, which we will represent by the symbol p. The total flux cut by all of the conductors in series in each path is equal to

$$\frac{Z}{a} \times \phi \times p$$

The rate at which the magnetic flux is cut per second is equal to the above product multiplied by the speed of the armature in revolutions per second, or the revolutions per minute divided by 60. The rate at which the magnetic flux is cut per second divided by 10^8 gives the value of the induced electromotive force in volts, or

$$E = \frac{Z \times \phi \times p \times \text{r.p.m.}}{a \times 10^8 \times 60}$$

In the above equation, r.p.m. represents the revolutions per minute of the armature.

Example.—A four-pole machine has a simplex wave winding of 188 conductors; it is revolved at a speed of 1000 revolutions per minute; and the magnetic flux per pole is 2,000,000 maxwells. What is the value of the induced electromotive force?

Solution.—Substituting directly in the above equation and remembering the value of the number of paths a is 2, gives

$$E = \frac{188 \times 2 \times 10^6 \times 4 \times 1000}{2 \times 10^8 \times 60}$$

$$= 125.3 \text{ volts}$$

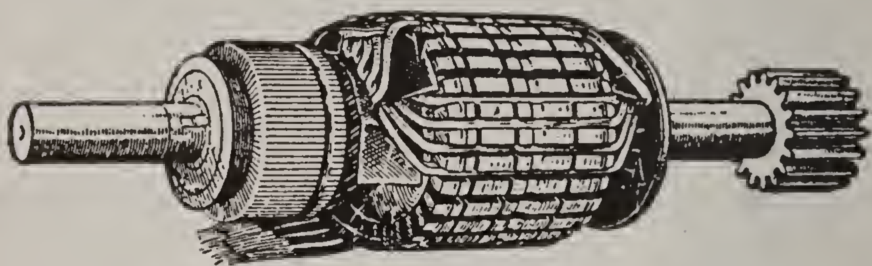


Figure 40.—Partially Wound Armature.

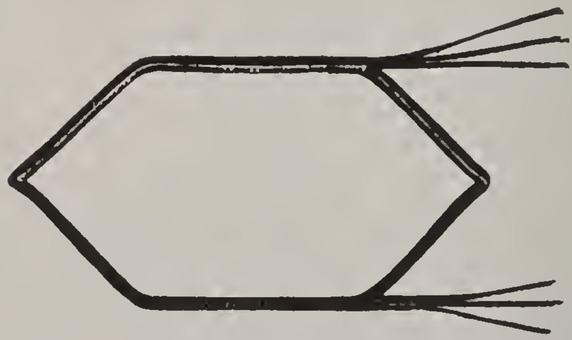


Figure 41.—Armature Coil Composed of Three Elements.

Two-Layer Windings.—An inspection of any of the armature-winding diagrams in Figures 32, 33, 34, etc., will show that the end connections of successive conductors proceed alternately in opposite directions. It is apparent that all of the conductors in a slotted armature cannot lay in the same layer as in smooth core armatures, because of the difficulty in crossing

end connections. This difficulty is overcome by placing one side of an element in the upper part of the slot and the other side in the lower part of the slot, as shown in Figure 40. One or more elements may be bound together, as shown in Figure 41, and form what is called a *coil.*

CHAPTER VI

COMMERCIAL TYPES OF DIRECT-CURRENT MOTORS

Fundamental Principle of the Direct-Current Motor.—If a wire, in which there is a direct current, be placed in a magnetic field in such a position that the center of the wire does not correspond in position to the direction of the magnetic field, there will be a force acting on the wire, due to the action of the current in the wire and the magnetic field upon each other. This force is present in the generator when the machine is operating and there is a current in the armature, and it tends to cause the armature to revolve in the opposite direction to that in which the steam engine, or other prime mover, is rotating the armature. If there is an increase in the strength of the magnetic field or an increase in the value of the current in the wire, the position of the two with respect to each other remaining constant, there will be an increase in the force tending to move them with respect to each other. The value of the force between the magnetic field and the wire depends upon their relative positions; it is a maximum when the center of the wire and the direction of the magnetic field are at right angles to each other, and a minimum when the center of the wire and the direction of the magnetic field are parallel to each other.

Fleming's Left-Hand, or Motor, Rule.—There is a definite relation between the direction of the current

in a wire placed in a magnetic field, the direction of the magnetic field, and the direction of the force tending to move the wire with respect to the magnetic field. *If the thumb and first and second fingers of the left hand be placed at right angles to each other,* as shown in Figure 42, *the second finger pointing in the direction of the current in the conductor, and the first finger in the direction of the magnetic field, then the thumb will point in the direction in which the conductor will tend to move.* This simple rule is

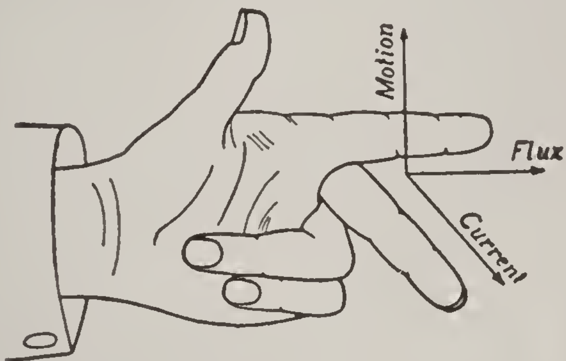


Figure 42.—Relation of Motion, Current and Magneto Field.

known as Fleming's left-hand, or motor, rule. If the direction of current in the wire be reversed, the direction of the magnetic field remaining constant, the direction of the force acting on the conductor will be reversed; or, if the direction of the magnetic field be reversed, the direction of current in the wire remaining the same, the direction of the force on the wire will be reversed. If, however, the direction of the current in the wire and the direction of the magnetic field are both reversed, the direction of the force on the wire will remain the same.

Generator and Motor Interchangeable.—The essential parts of a direct-current motor are identical with those of a generator, namely, an armature and a

magnetic field. The connection of the wires on the surface of the armature to the external circuit is made by means of a commutator which serves to reverse the current in the various parts of the armature winding at the proper time so that the force acting on the various wires tends to produce rotation in the same direction, and, as a result, continuous rotation of the armature is produced. Any direct-current generator may be used as a direct-current motor, or *vice versa,* their construction being practically the same.

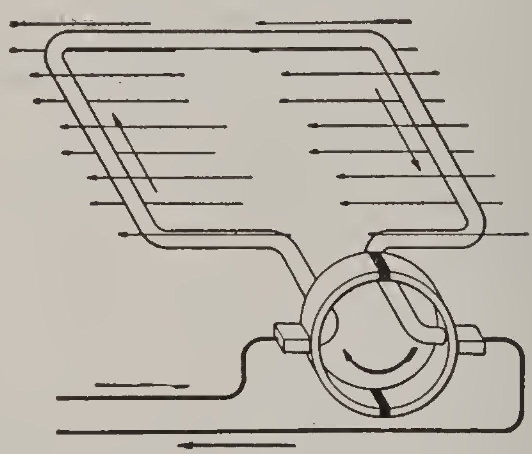


Figure 43.—Loop of Wire with Two-Part Commutator.

Operation of Two-Part Commutator.—If a single loop of wire be mounted on an axis which is at right angles to the direction of a magnetic field, as shown in Figure 43, and a current be supplied to the coil by means of a two-part commutator and two brushes which rest upon the commutator exactly opposite each other, there will be a force acting on the sides and ends of the coil. The direction of the force acting on any part of the coil for all the different positions the coil may occupy when it turns on the axis

supporting it may be determined by a simple application of Fleming's left-hand, or motor, rule. Remembering that the force acting on the conductor is always perpendicular to the direction of the magnetic field, we may proceed to investigate the force acting on the coil for various positions. The resultant force acting on the two ends of the coil which tends to produce rotation will be zero for all positions of the coil. The force acting on the two sides of the coil will be equal in value for all positions, but the direction of the force on the two sides will be exactly opposite each other. If the force on one side tends to move that side of the coil up, then the force on the other side tends to move that side down. The force acting on one side will always be up and the force on the other side will always be down, and they will remain constant in value so long as there is no change in the strength of the magnetic field or in the value of the current. These forces on opposite sides of the coil being in opposite directions tend to rotate the coil, but the tendency for rotation is not constant in value for all positions of the coil. When the coil is in a horizontal position, the effect of the forces in tending to produce rotation is a maximum, because the two sides are then moving, as the coil rotates, perpendicular to the direction of the magnetic field; but for any other position of the coil with respect to the direction of the magnetic field, the effect of the forces tending to produce rotation will be less, and this effect will continue to decrease as the coil moves from a position parallel to the field toward a position perpendicular to the field where the force producing rotation will be zero. The relation of the forces tending to rotate the coil for

different positions of one complete revolution may be represented by a curve, as shown in Figure 44, in which points along the horizontal line correspond to different positions of the coil in degrees as measured from a position perpendicular to the direction of the magnetic field, and the relation of the lengths of the vertical lines correspond to the relation between the values of the forces tending to produce rotation for the different positions.

Just at the instant that the coil becomes perpendicular to the magnetic field, the two commutator segments exchange positions with respect to the

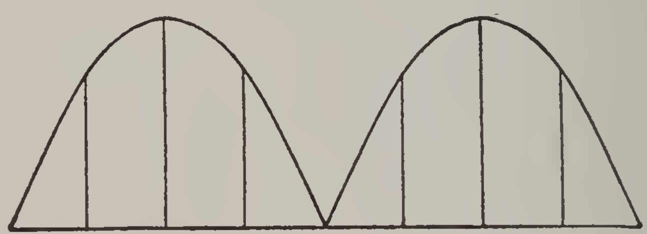


Figure 44.—Curve Showing Variation in Force Acting on Loop as it Revolves in a Magnetic Field.

brushes, and as a result the current in the coil reverses in direction. With a reversal in the direction of current in the coil, there is a reversal in the direction of the forces acting on the two sides, so that they tend to move across the magnetic field in opposite directions to what they did before the current in the coil was reversed in direction.

It is obvious from the above discussion that the force acting on the coil tends to produce a continuous rotation, provided the magnetic field does not change in direction, and that the brushes are properly placed on the commutator. The value of this force, however, fluctuates in value, it being zero when the coil is perpendicular to the direction of the magnetic field,

and if the coil should happen to stop in this position, there would be no tendency for rotation no matter how much current there was in the coil or how strong the magnetic field. Such an arrangement would not be at all satisfactory on account of the fluctuation in the turning force on the coil and also because this force is zero for two positions of the coil in each revolution. The turning force may be made nearer constant in value and at no time zero by means of more coils and more commutator segments.

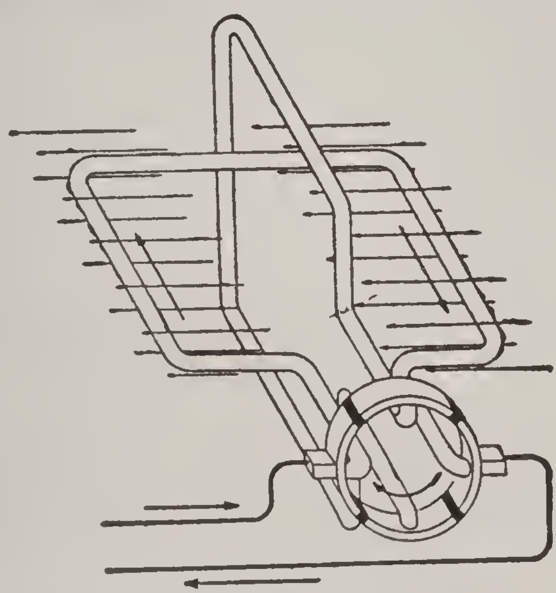


Figure 45.—Two Loops of Wire with Four-Part Commutator.

Multiple-Coil Armatures.—If two coils of wire, similar to the one described in the previous section, be mounted on an axis at right angles to each other with the four terminals connected to a four-part commutator, the terminals of each coil being connected to opposite segments, as shown in Figure 45, then the force tending to turn the two coils will pulsate in value as follows: Since the two coils are at right angles to each other, the forces acting on them will likewise be at right angles to

each other. If the currents in the two coils are equal in value, and assuming they remain so for one complete revolution, then the forces acting on the two coils may be represented by two curves, as shown in Figure 46. Both coils do not carry current at the same time, since they are connected to independent commutator segments, and the brushes rest on segments exactly opposite each other. Each coil is connected in circuit for each revolution only one-half of the time, but this time is split into two parts and each independent connection lasts only for

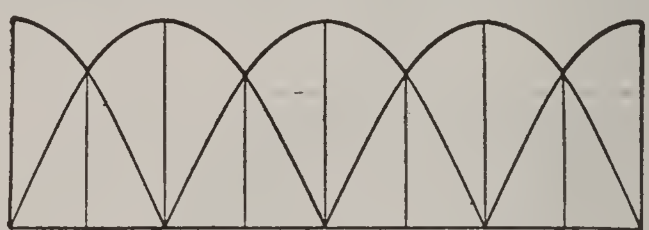


Figure 46.—Curves Showing the Relation of the Forces Acting on Two Loops at Right Angles to Each Other as They Revolve in a Magnetic Field.

one-fourth of a revolution. Now, by properly placing the brushes, it is possible to get a continuous turning force acting on the combination of coils, and the best position for the brushes is such that one coil is disconnected and the other one connected to the external circuit when they are making the same angle with the direction of the magnetic field, namely 45 degrees. This position of the brushes corresponds to the point where the curves cross each other, as shown in Figure 46, and the resultant force acting on the two coils may be represented by the upper parts of the curves, or the shaded portion.

By increasing the number of coils and commutator segments, the force acting on the coils will become nearer constant in value. This type of armature is

not satisfactory for direct-current motors as only those coils whose commutator segments are under the brushes at any particular time are in use. An armature winding of this type is called an *open-circuit* winding.

A better form of winding for direct-current motors, called a *closed-circuit* winding, makes use of all of the coils all of the time except when

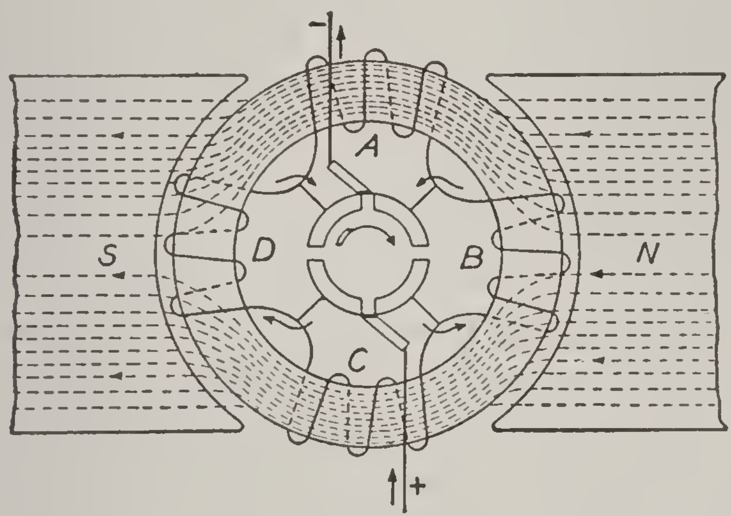


Figure 47.—Simple Closed-Circuit Ring Winding.

the two commutator segments to which a coil is connected are in contact with a brush or brushes of the same polarity. One of the simplest forms of closed-circuit windings is shown in Figure 47, which consists of a ring with four coils wound about it and interconnected by means of four commutator segments as shown in the figure. For convenience in referring to these coils they are designated by the letters *A*, *B*. *C*, and *D*. The two coils *A* and *C* are short-circuited by the two brushes when they are in the positions shown in the figure. An instant later, however, coil *A* is in series with coil *B*

on the right-hand side, and coil C is in series with coil D on the left-hand side, and this connection remains until coils B and D are short-circuited by the brushes. An instant later coil D is in series with coil A on the right-hand side, and coil B is in series with coil C on the left-hand side. It is apparent that the coils opposite each other are short-circuited by the brushes at the same time when they are symmetrically arranged, as in this case, and as one coil leaves the right-hand circuit and enters the left-hand circuit at the lower brush, there is a coil leaving the left-hand circuit and entering the right-hand circuit at the upper brush. With this arrangement of coils and commutator segments, all of the coils are in circuit with the external circuit all of the time except when they are short-circuited by the brushes. If the position of the brushes is such that the coils are moving parallel to the magnetic field when they are short-circuited, there will be no decrease in the total force acting on the combination tending to produce rotation. The direction of the current in each coil when it has moved from the shirt-circuited position is opposite to what it was just before it reached this position, hence, the movement of the coil with respect to the magnetic field is reversed, that is, if it was tending to move up or down before short-circuited, it tends to move down or up after short-circuit. The total force tending to produce rotation at any instant is equal to the sum of the forces produced by each of the coils. When the coils are symmetrically placed with respect to each other, the force exerted by any two which are exactly opposite each other might be thought of as being due to a single coil having a number of turns equal to the sum of the turns in

the two coils, The four coils in Figure 47 are symmetrically arranged and may be treated as two coils instead of four. The force exerted on these two coils may be represented by two curves *A* and *B*, as shown in Figure 48, and the total force at any time will be equal to the sum of the forces on the two coils, since they are both in circuit all the time except when they are short-circuited by the brushes, and then the force exerted by that particular coil is zero because it is then moving parallel to the magnetic

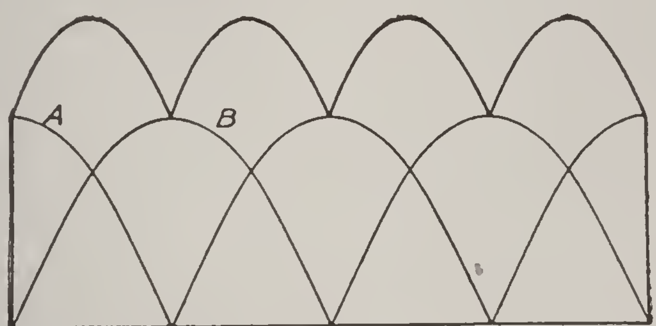


Figure 48.—Curves Showing the Relation of the Forces Acting on Four Coils Interconnected with Four Commutator Segments.

field. This total force may be represented by a third curve whose height at any point is equal to the sum of the heighths of the two curves *A* and *B*. From this figure it is readily seen that the force tending to produce rotation is not constant in value, but it fluctuates between a minimum value equal to the maximum force produced by a single coil and a maximum value equal to the combined values of the forces produced by the coils when they are each midway between their positions of minimum and maximum force. The number of pulsations in the force per revolution may be increased by increasing the number of coils and commutator segments, and an increase in the number of pulsations per revolution

will result in a decrease in the difference between the maximum and the minimum values of the resultant force tending to produce rotation. Thus, with an increase in the number of coils and commutator segments, the resultant force becomes nearer constant in value, and the machine is capable of developing a fairly constant turning effort.

The type of armature used in the above description, which is called a *ring type,* is not used very extensively at present, but, on account of the simplicity in its construction and the connections of the coils, its operation is much more readily understood than that of the drum type, although the fundamental principle of both is exactly the same and, after you have thoroughly mastered the operation of the ring type, the operation of the drum type, whether it be lap or wave wound, may be easily followed.

Types of Magnetic Fields.—In the majority of cases the magnetic field of a motor is produced by electromagnets, although a magnetic field may be produced by powerful permanent horseshoe magnets. Small machines are usually bipolar, that is, they have one north pole and one south pole which create the magnetic field in which the armature rotates. These magnetic fields assume a number of different forms, a few of which are shown in Figure 49.

In large machines it is customary to use multipolar field magnets in which any even number of magnetic poles are arranged alternately around the armature, as shown in Figure 50, which depicts an eight-pole machine.

The magnetic circuit of a motor, whose magnetic field is created by electromagnets, usually consists of five parts, see Figure 50, as follows: *First,* the field

cores C are the parts about which the coils carrying the magnetizing current are wound. *Second*, the yoke Y connects the field cores together at the outer end, as shown in the figure, and serves the double purpose of completing the magnetic circuit between the

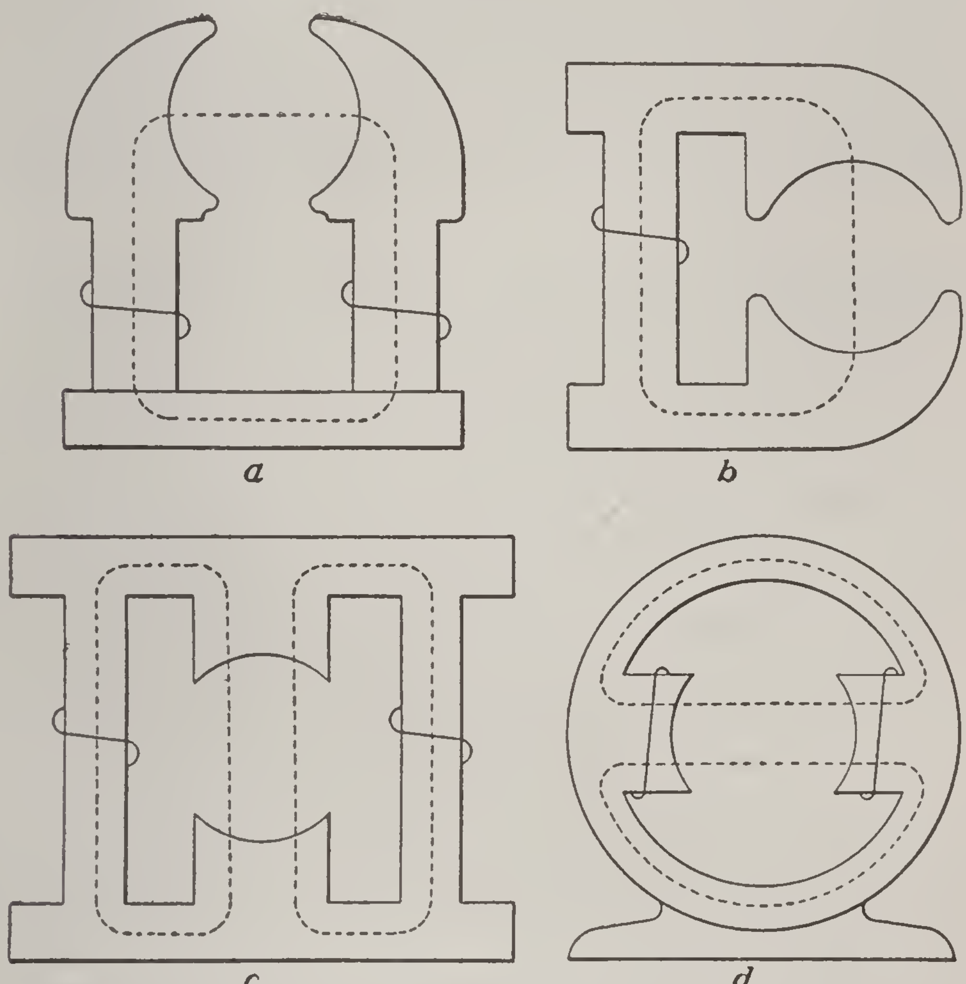


Figure 49.—Types of Two-Pole Magnetic Fields.

field cores and of providing the necessary mechanical supports for the cores. In some machines there is no yoke in the magnetic circuit, see Figure 49. *Third*, the pole pieces P are the parts of the magnetic circuit next to the armature. They are usually cut to conform to the curvature of the armature. They may

be formed by properly shaping the ends of the field cores, or they may be an entirely different piece of metal than the ends of the field cores, being fastened to the field cores by means of bolts. The surface of the pole pieces next to the armature is called the *pole face;* and the projecting edges, when so constructed, are called the *pole tips. Fourth,* the armature core *A* conducts the magnetic flux between air gaps, and at the same time serves as a mechanical

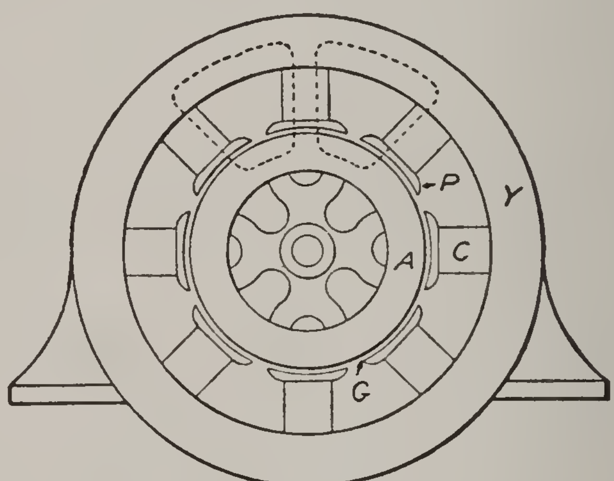


Figure 50.—Eight-Pole Magnetic Field.

support for the armature winding. *Fifth,* the air gap *G* is the intervening space between the pole piece and the armature.

When the field windings are placed on the magnetic circuit as shown in Figures 49*a*, and 49*d*, the magnetomotive force created by the current in one coil is in series with the magnetomotive force created by the current in the other coil, or the magnetomotive force on any magnetic circuit is that produced by the two coils in series. If the field windings be placed on the magnetic circuit as shown in Figure 49*c*, the magnetomotive force acting on any magnetic circuit

will be equal to that produced by a single coil. When the field windings are placed as shown in Figures 49*a* and 49*d*, only one-half as many ampere turns per coil will be required as would be required if the coils were placed as shown in Figure 49*c*, assuming the total reluctance in the two cases to be the same. The magnetomotive force produced by the field coils in Figure 49*d* acts upon two magnetic circuits and, as a result, it is twice as effective as it would be if the coils were placed about the yoke between the poles.

Materials Used in the Construction of the Magnetic Circuit of a Motor.—There are four materials that are commonly used in the construction of the magnetic circuit of a motor—wrought iron, cast iron, cast steel, and sheet steel. There are a number of factors which govern the selection of the materials to be used in a particular machine, such as initial cost, weight, efficiency demanded by purchaser, regulation, etc.

The cheapest of the above materials is cast iron, but its magnetic properties are poorer than any of the others, so the saving in the initial cost of the iron per pound might be more than overbalanced by the fact that a larger bulk of cast iron would be required to form a certain magnetic circuit than would be required if wrought iron, for example, were used. There would also be an increase in the cost of copper required to magnetize the magnetic circuit of large area, since the length of each turn would be more than if a better material were used or the area of the magnetic circuit were reduced.

Steel, on the other hand, is the best magnetic material, and at the same time the most expensive. It is used where economy in weight and reduction in

cross-section are desired. Machines used aboard ships, on electric automobiles, etc., are frequently made of cast or laminated steel on account of the large reduction in weight, which is a more important factor than the initial cost.

The magnetic circuits of motors are, as a rule, constructed of more than one material. Thus, the field cores may be of wrought iron, as that means a saving in copper, since the length of the wire per turn would be less than if cast iron were used; the yoke may be made of cast iron, as its area can be made larger than the field cores, and this increase in area will provide an ample magnetic circuit and also the necessary mechanical strength to support the field cores. The armature core is usually constructed of sheet metal so as to reduce the eddy-current loss to a minimum; the pole pieces may be a part of the field cores, and may be cast or laminated and bolted to the ends of the field cores. Numerous other combinations are used in the construction of the magnetic circuit of a motor, but the above suggestions serve to illustrate some of the more important considerations involved in a proper selection of the materials for a particular case.

Magnetic Leakage.—The total number of magnetic lines established by the field current of a motor do not pass through the armature core and, therefore, they are not all useful in the operation of the motor. The ratio of the total number of magnetic lines that are produced to the number that are actually useful in the operation of the motor is called the *coefficient of dispersion.* The value of this coefficient is always greater than one, as there are always more lines of force produced than are actually useful. It is always

desirable to have the value of the dispersion coefficient as low as possible, and this is accomplished by constructing the magnetic circuit so it will have no abrupt bends, be short as possible, and have a low reluctance. The coefficient of dispersion can be reduced by placing the field winding upon or near that part of the magnetic circuit having the greatest reluctance and by so shaping the magnetic circuit that the paths conducting the magnetic flux, which is not useful, will have a high reluctance as compared to the paths conducting the useful magnetic flux.

Excitation of Direct-Current Motors.—Direct-current motors may be divided into three classes according to the method employed in exciting the field magnets. These are:

(a) Shunt motors
(b) Series motors
(c) Compound motors

(a) The field winding of a shunt motor consists of a relatively large number of turns of small wire connected directly across the terminals of the machine, or the circuit to which the machine is connected. A rheostat may be connected in series with the field winding, which may be used in adjusting the value of the current, or no rheostat may be used at all and the field current allowed to vary with the voltage impressed across its terminals and the change in resistance of the field winding, due to a change in its temperature. The connections of a shunt motor are shown diagrammatically in Figure 51. The current in the field winding is independent of the current in the armature circuit so long as a change in armature current produces no change in the voltage impressed on the shunt field winding.

(b) In the case of the series motor, the field winding consists of a relatively few turns of large wire connected directly in series with the armature, as shown diagrammatically in Figure 52. The current in the field winding is the same as the current in the armature, and the strength of the magnetic field

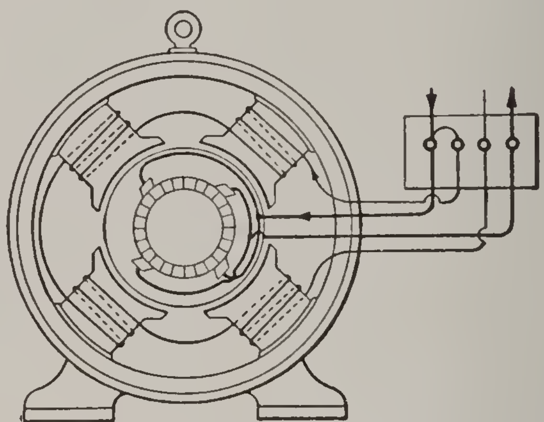


Figure 51.—Diagram of Shunt Motor Connections.

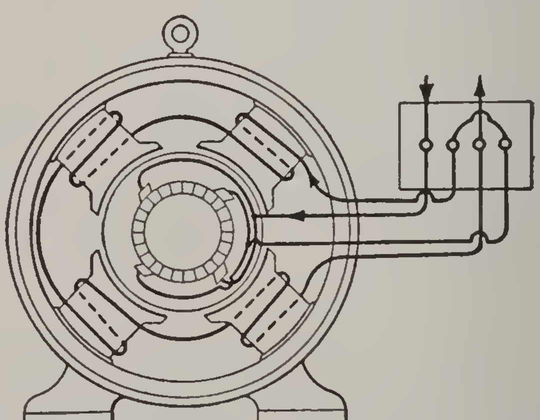


Figure 52.—Diagram of Series Motor Connections.

of the machines varies with the armature current. The field strength does not increase as rapidly as the current in the field winding, due to the fact that the reluctance of the magnetic circuit of the machine increases with an increase in the magnetic flux. In some cases, there is a resistance connected in parallel with the series field winding and only a part

of the armature current passes through the field, the total current dividing inversely as the resistance of the two branches of the divided circuit.

(c) The field windings of a compound motor are a combination of the shunt and series winding, as shown diagrammatically in Figures 53*a* and 53*b*. The

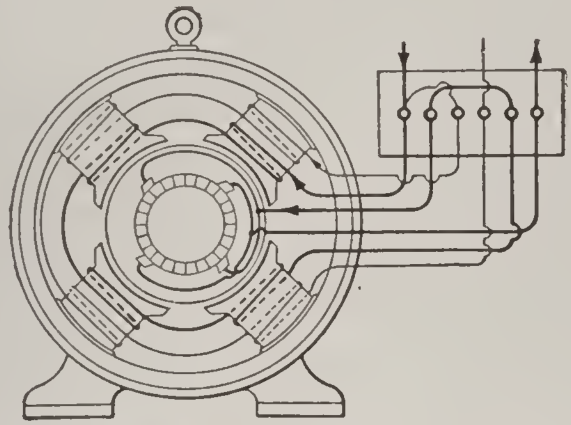


Figure 53*a*.—Diagram Cumulative Compound Motor.

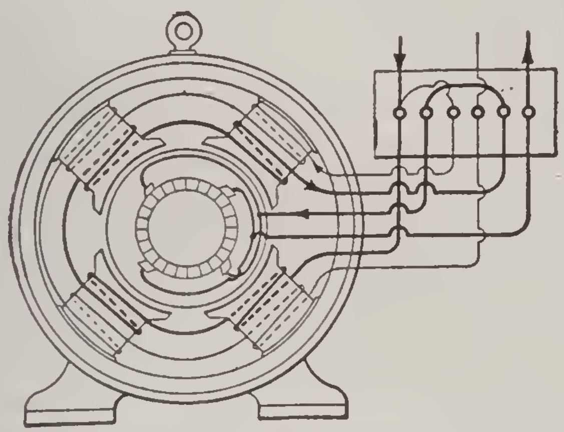


Figure 53*b*.—Diagram Differential Compound Motor.

magnetic effect of these two windings may aid or oppose each other, depending upon the manner in which they are connected. When the magnetizing action of the series and shunt field windings both act in the same direction about the magnetic circuit, the machine is called a *cumulative compound motor;* and when the magnetizing action of the series and shunt

field windings are in opposite directions about the magnetic circuit, the machine is called a *differential compound motor*. In the case of the cumulative compound motor, the strength of the magnetic field increases with an increase in series field current, since the two magnetizing effects act together; and in the case of the differential compound motor, the strength of the magnetic field decreases with an increase in series field current, since the two magnetizing effects act in opposite directions.

Direction of Rotation of Machines When Changed from a Generator to a Motor.—The direction in which a direct-current generator will operate when it is changed to a motor may be easily determined by the following simple relations.

First, if the direction of the armature current and the direction of the magnetic flux through the magnet circuit of the machine both remain unchanged, or both are changed, when the machine is changed from a generator to a motor, the direction of rotation will be reversed.

Second, if the direction of the armature current or the direction of the magnetic flux through the magnetic circuit are either reversed, but not both, when the machine is changed from a generator to a motor, the direction of rotation will remain unchanged.

Third, to reverse the direction of rotation of a motor, it is necessary to reverse either the direction of the armature current or the magnetic flux, but not both.

If a shunt generator be changed to a motor, the polarity of the terminals remaining the same, the direction of rotation will remain unchanged, because the direction of the shunt field current remains the same

and the armature current reverses in direction, it flowing from the negative to the positive terminal within the generator and from the positive to the negative terminal within the motor. If, however, the polarity of the machine be reversed when it is changed from a generator to a motor, the direction of rotation will remain unchanged, because the direction of the shunt current is reversed and the direction of the armature current remains constant.

This leads to the general statement that a shunt generator when changed to a motor will operate in the same direction, regardless of the polarity of its terminals, provided there is no change in the connection of the armature and field windings with respect to each other.

If a series generator be changed to a motor, the polarity of the terminals remaining the same, both the armature current and the direction of the magnetic flux will reverse in direction, and the direction of rotation will reverse. If the polarity of the machine changes when it is changed from a generator to a motor, then the armature current and the direction of the magnetic field will remain unchanged, and the direction of rotation will be reversed. This leads to the general statement that a series generator when changed to a motor will operate in the opposite direction, regardless of the polarity of its terminals, provided there is no change in the connections of the armature and field windings with respect to each other.

If a cumulative compound generator be changed to a motor without any change in the connections of the field windings, the machine will become a differential compound motor. Likewise, if the ma-

chine is a differential compound generator, it will be a cumulative compound motor. The direction of rotation of such a machine when changed to a motor will depend upon the relative effects of the series and the shunt field windings. For example, a differential compound motor may start up under the influence of the series winding and, after the shunt field current has had time to build up in value, the armature may stop and start to rotate in the opposite direction.

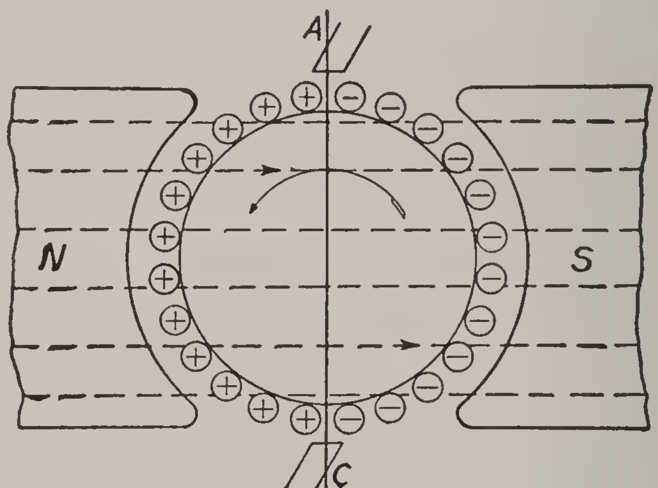


Figure 54.—Magnetic Field of Motor Due to Field Current Alone.

Armature Reaction in a Motor.—When there is a current in the armature winding of a motor there is a magnetizing effect produced, due to this current, which acts upon the main magnetic field of the motor. This effect is called *armature reaction.* The effect of this magnetizing action, due to the armature current, may be illustrated as follows: Take a simple two-pole drum armature with a number of wires uniformly distributed over its surface and imagine it placed in a bipolar magnetic field, as shown in Figure 54, which shows a cross-section through the armature and fields. Current is supplied to the armature

winding by means of two brushes which rest upon a commutator, and these brushes are placed in such a position that all of the wires on the right of a vertical line through the center of the armature have a current in them from the surface of the paper. If the magnetic poles have the polarity indicated in the figure, then the armature will tend to revolve in a counterclockwise direction, as indicated by the curved arrow. This direction of rotation may be easily de-

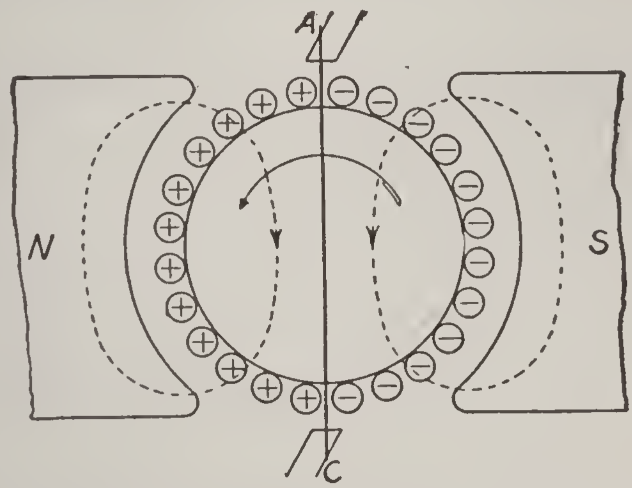


Figure 55.—Magnetic Field of Motor Due to Armature Current Alone.

termined by an application of Fleming's left-hand, or motor, rule. The plane, marked $A\ C$ in the figure, which is perpendicular to the axis of the poles and also the sheet of paper, is called the *normal neutral plane.* This normal neutral plane is perpendicular to the magnetic flux when there is no current in the armature winding. Now imagine the field current of the motor is zero and that a current is sent through the armature winding from some outside source. The current in the armature winding produces a magnetic field whose general direction through the armature core is downward, as shown in Figure 55, when

the current is in the direction indicated in the figure. Since the magnetizing effects of the armature current and the field current are present at the same time, they combine and form a resultant magnetizing effect which produces a magnetic field whose general direction is similar to that shown in Figure 56. As a result of the magnetizing action of the armature current, the magnetic field of a motor is twisted in a direction opposite to the direction of rotation of the

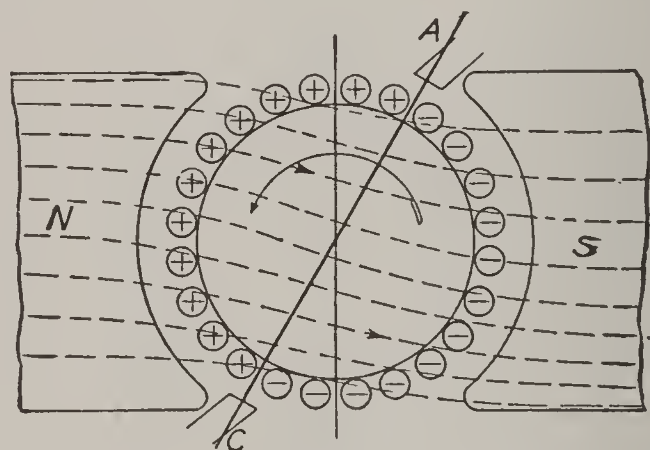


Figure 56.—Resultant Magnetic Field of a Motor.

armature, which is just the reverse of what occurs in the case of the generator. This twisting of the magnetic field results in the neutral plane, which is a plane perpendicular to the direction of the magnetic field, being moved back of the normal neutral plane, as shown by the line *A C* in Figure 56.

Proper Position of the Brushes on a Direct-Current Motor.—In order that the armature produces its maximum turning effort for a given armature current and magnetic field, it is necessary that the brushes be placed on the commutator in such a position that the current in the conductors on the surface of the armature reverses in direction when the wires are moving

parallel to the magnetic field, or when they are in the neutral plane. It is necessary then that the brushes be moved backward, or opposite to the direction of rotation in the case of the motor, as the current in the armature winding increases, which increases the amount the neutral plane is twisted or moved from the position it occupies when there is no current in the armature winding. The brushes are usually moved a little farther back than the neu-

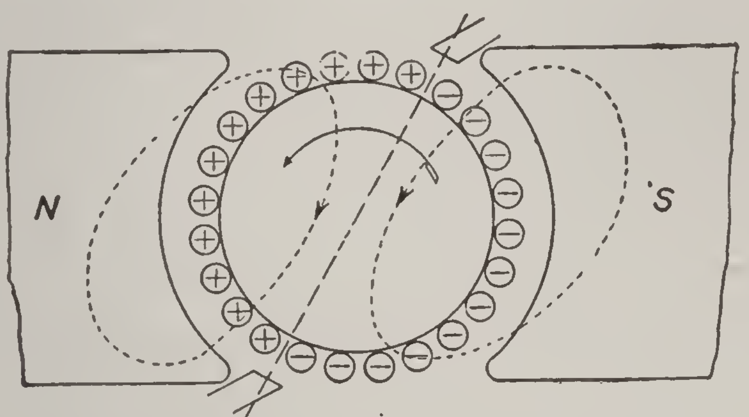


Figure 57.—Magnetic Field of Motor Due to Armature Current Alone.

tral plane, although there is a slight reduction in the turning effort, in order to improve commutation, as explained in the section on "Commutation." The position occupied by the brushes is called the *commutating plane.* The position the brushes actually occupy with respect to the poles of the machine will be quite different than that indicated in the figures dealing with armature reaction, on account of the end connections of the wires to the commutator segments, but the direction of the current in the different wires will be the same as indicated in the figures.

With a change in the position of the brushes, there will be a change in the direction of the current in

some of the wires on the surface of the armature. Thus, if the brushes are moved opposite to the direction the armature tends to rotate, as shown in Figure 56, the direction of the current in the wires contained in the angle through which the brushes are moved will change, and the magnetic effect of a current in the armature will no longer be in a direction at right angles to the magnetizing effect of the field current, but in a direction similar to that shown in Figure 57. This magnetizing effect of the armature can be thought of as made up of two parts, one part acting perpendicular to the magnetizing effect of the field current, called the *cross-magnetizing effect,* and the other part acting parallel to the magnetizing effect of the field current, called the *demagnetizing effect.* The demagnetizing effect of the armature current tends to weaken the magnetic field of the motor and the cross-magnetizing effect tends to distort or twist the magnetic field in a direction opposite to the direction in which the armature rotates.

The angle between the commutating plane and the normal neutral plane is called the *angle of lag* in the case of the motor, because the brushes are moved backward or given a lag with respect to the normal neutral plane, and it is called the *angle of lead* in the case of a generator, because the brushes are moved forward or given an angle of lead with respect to the normal neutral plane.

Demagnetizing and Cross-Magnetizing Ampere-Turns.—The relative positions of the commutating planes for a generator and a motor are shown in Figure 58, the full line representing the commutating plane of the motor and the dotted line representing the commutating plane of the generator. The direc-

tion of current in the armature wires corresponds to the motor connections and the direction of rotation will be as indicated by the curved arrow. The wires between the two commutating planes on one side of the armature can be thought of as being in series with the wires between the two commutating planes on the opposite side of the armature and forming a number of complete turns about the armature core. The remaining wires may be thought of as forming

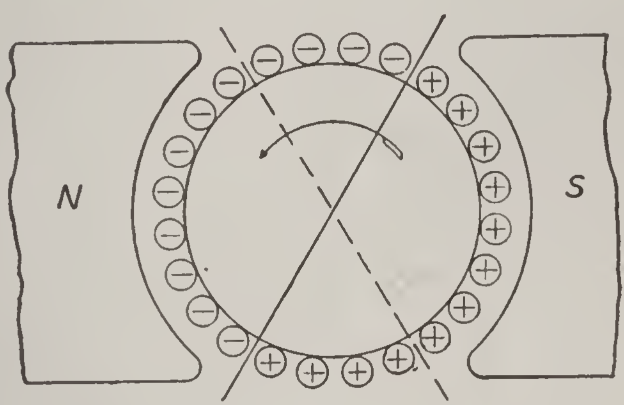


Figure 58.—Demagnetizing and Cross-Magnetizing Ampere-Turns.

a second set of turns. The product of the turns in the angle between the commutating planes and the current in each of these turns gives the value of what is called the *demagnetizing ampere-turns*, because their effect is to produce a weakening of the magnetic field of the machine. The product of the remaining turns and the current they carry gives the value of what is called the *cross-magnetizing ampere-turns*, because they act at right angles to the magnetizing effect of the field current of the machine. The turns in the angle between the commutating planes are called the *demagnetizing*, or *back-turns*, and the remaining turns are called the *cross-turns*.

Commutation.—The process of commutation can be explained by reference to a simplified diagram of the armature winding as shown in Figure 59. The commutator segments are marked C_1, C_2, C_3, etc., while the various parts of the armature winding, called *elements* and marked *1*, *2*, *3*, etc., are shown connected in series, the terminals of these elements being connected to the commutator segments in regular order. The position of the neutral plane is repre-

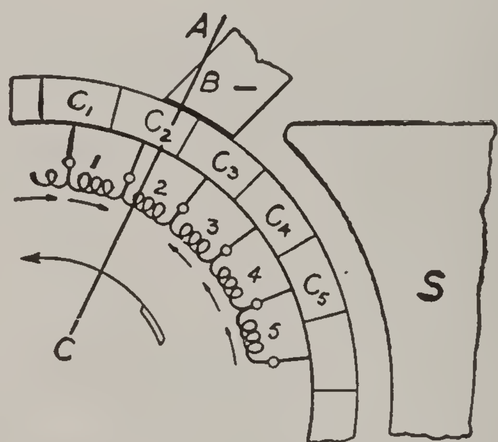


Figure 59.—Process of Commutation.

sented by the line AC, the direction of rotation by the large curved arrow, the direction of the current in the various elements of the winding by the small arrows, and the polarity of the pole, shown to the right, by the letter *S*. With a direction of current in the elements of the armature winding corresponding to that shown in the figure, the brush *B* must be negative.

Now as the armature rotates, the commutator segments in turn pass under the brush, and if the arc of contact of the brush on the commutator is greater than the width of the insulation between the commutator segments, which should always be the case,

then an element of the armature winding will be short-circuited when the brush is in contact with the two segments to which the terminals of the element are connected. When an element becomes short-circuited by the brush, it is no longer directly in series with the elements of the armature winding to its right or left, and the current in the element will drop to zero value, provided there is no electromotive force induced in the element or it is moving parallel to the magnetic field, but it does not do so instantly on account of a property of the element, called its *inductance*, which tends to prolong the current. As the armature rotates, one of the commutator segments to which the short-circuited element is connected moves out from under the edge of the brush and the short-circuit on the element is removed, and the element becomes a part of the circuit through the armature to the left of the brush. When the element, which was short-circuited, becomes a part of the left-hand path through the armature, it must carry the same current the other elements in that path carry regardless of the value of the electromotive force being generated in the element, because they are all directly in series. Now, if there is zero current in the short-circuited element, just as the short-circuit is removed by one of the segments moving from under the brush, the current in the element must increase almost instantly to a value equal to the current in the elements in the left-hand circuit through the armature. A property of the element—inductance—opposes this sudden increase in current and, as a result, there is a tendency for an arc to form between the edge of the brush and the commutator segment which is breaking contact with the brush until the current in

the element, whose short-circuit is being removed, has reached its proper value or the inductance of the coil has been overcome. This condition of affairs would result in a continuous sparking at the brushes, which would not only represent a loss but it would be injurious to both the commutator and the brushes.

Sparking due to the cause just mentioned can be reduced and practically overcome by moving the brushes back of the neutral plane. When the brushes are thus changed, there will be an electromotive force induced in the element of the winding while it is short-circuited and this electromotive force will be in such a direction as to produce a current in the element in the same direction as the current in the elements to the left of the brush. The induced electromotive force in the element which is short-circuited also causes the current in the element, when it comes into the short-circuited position, to decrease to zero value in a less time than it would if there were no induced electromotive force in the element. The above results, due to the effect of the induced electromotive force in the short-circuited element, indicates that the inductance of the element is overcome while it is short-circuited, and there will be a current of the proper value already established in the element when it becomes a part of the left-hand circuit. Moving the brushes back of the neutral plane results in a decrease in turning effort the armature is capable of producing, but this is more than offset by the advantages of better commutation.

The winding which has been used in explaining commutation is perhaps the simplest form it is possible to have, but the fundamental principles involved are practically the same in every case.

In certain types of lap windings the elements are connected to segments which are not adjacent to each other but may be several segments apart. In such a winding, it is necessary that the arc of contact of the brushes cover several segments in order that the various elements may be properly commutated. The time of short-circuit of the different elements must be such that it is possible to reverse the current in the element.

In the case of wave windings, the elements are connected to commutator segments which are approximately 360 electrical degrees apart, and instead of an element being short-circuited by a single brush, as in the lap winding, it is shorted by two brushes of the same polarity, these brushes being connected externally by a heavy conductor, called the *brush ring*.

The brushes on a machine may be adjusted to give practically perfect commutation for a given field current and armature current, but, if either the field or the armature current, or both, change in value, there will be a change in the degree to which the resultant magnetic field of the machine is twisted, and, as a result, the commutation will not be as satisfactory as before the change. In order to have as good commutation as possible at all times, it would be necessary to move the brushes whenever there is a change in the position of the neutral plane.

Commutation is improved, somewhat, by increasing the resistance of the short-circuited element, although there is a slight decrease in efficiency, due to the introduction of this resistance in the main armature circuit. When the resistance of the short-circuited element is increased, the current can be reversed in direction in a shorter time than with the lower

resistance. Carbon brushes have the advantage of giving better commutation than copper brushes, on account of them offering a higher resistance in the path of the short-circuited element than the copper brushes. They are sometimes copper-plated so as to reduce their resistance in the main circuit of the machine. In some cases, as in the series alternating-current motor, a small resistance is introduced in the connection between the commutator segments and the connections of the different elements.

Means of Reducing Armature Reaction.—Armature reaction interferes with the satisfactory operation of the motor and it is always desirable to reduce it to a minimum where possible. There are a number of methods of bringing about a reduction in armature reaction, some of the more important ones being:

(a) By constructing the machine with a relatively long air gap
(b) By slotting the pole cores parallel to the axis of the armature core
(c) By properly shaping the pole pieces
(d) By placing a special winding in slots or openings cut in the pole shoes
(e) By auxiliary magnetic poles

(a) Increasing the length of the air gap increases the reluctance of the magnetic circuit and more ampere-turns are required to produce the necessary magnetic flux than would be required with a shorter air gap. The effect of the cross ampere turns on the armature in distorting the magnetic field is not so great when there is a large number of ampere turns required per pole as it is with a smaller number of ampere turns per pole, as a result, the position of the neutral plane of the machine remains nearer constant.

(b) Cutting slots in the pole cores parallel to the axis of the armature core introduces a larger reluctance in the path upon which the cross-magnetizing ampere-turns act, but does not introduce anything

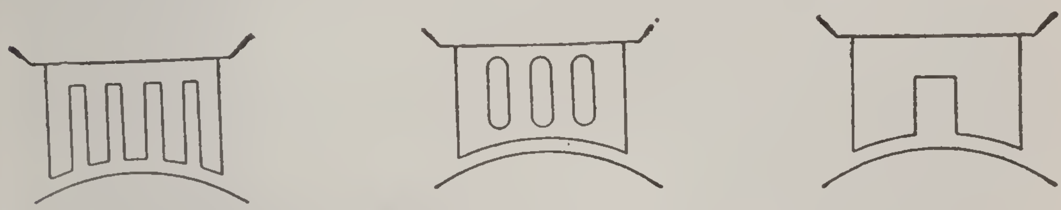


Figure 60.—Methods of Slotting Pole Cores.

like as great a reluctance in the main magnetic circuit of the machine. Cross-sections of pole cores embodying this principle are shown in Figure 60.

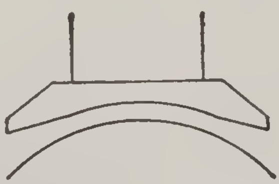


Figure 61.—Chamfered Pole Piece.

(c) The shifting of the magnetic flux across the pole shoes of the machine can be readily reduced by properly shaping the pole faces so that the parts of the air gap where the magnetic flux tends to become

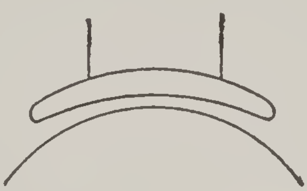


Figure 62.—Eccentric Pole Piece.

most dense will have the greater reluctance. Thus the pole tips may be chamfered, as in Figure 61, or the bore of the pole faces may be made eccentric with respect to the armature, as in Figure 62. Additional

reluctance at the pole tips may be provided by using a long thin tip, or, in the case of laminated poles, by using a stamping of the form shown in Figure 63, in which case the laminations are built up to the required thickness in such a manner that the projecting tips are on alternate sides. This construction may be used for the pole pieces alone and then bolted to a solid pole core.

(d) A winding may be imbedded in the slots cut in the pole pieces and a current sent through it in such a direction as to produce a magnetizing effect

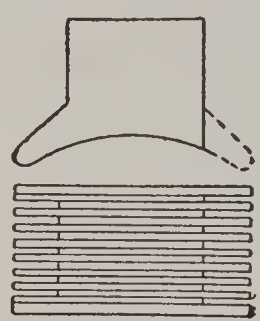


Figure 63.—Laminated Pole Core and Pole Piece.

opposite to that produced by the current in the wires on the surface of the armature. This winding is connected in series with the armature circuit and their magnetizing effects both vary at the same time, and if the two magnetizing effects neutralize each other for a certain load on the machine, they will practically neutralize for all loads, which results in the position of the neutral plane remaining practically constant and almost independent of the armature current.

(e) Auxiliary magnetic poles may be placed between the main magnetic poles of the machine and magnetized to such a polarity that they tend to counteract the effect of the cross-magnetizing ampere turns

on the armature. The windings on these poles, which are called *interpoles,* due to their position between the main poles, are connected in series with the armature and carry all or a definite portion of the armature current. This results in their magnetizing effect varying directly as the armature current, just as the effect of the cross-magnetizing ampere turns varies with the armature current, and, if the effects balance for one particular current, they will practically balance for all other currents and the position of the neutral plane of the magnetic field will remain almost constant. As explained in the section on "Commutation," it is desirable to have an electromotive force induced in the short-circuited element, in order to decrease the current to zero value in a shorter time and to establish a current of proper value in the opposite direction during the time of short-circuit. This induced electromotive force is produced by moving the brushes *backward* from the neutral plane in the case of a motor and *forward* from the neutral plane in the case of a generator. When interpoles are used, the magnetizing effect of the interpole windings are usually so adjusted as to more than compensate for the cross-magnetizing effect of the armature current, which results in a weak magnetic field being established under the interpoles. This weak magnetic field produces in the short-circuited element the necessary electromotive force to overcome the inductance of the element and there is no need of moving the brushes in order to have satisfactory commutation. When there is a change in the armature current, there is also a change in the magnetic field under the interpoles and a larger electromotive force is induced in the short-circuited element,

which readily takes care of the reversal of the larger current. If the direction of rotation of the armature is changed by reversing either the magnetic field or the armature current, the polarity of the interpole will still be such as to counteract the effect of the cross-magnetizing ampere turns on the armature and also assist in commutation as just described.

The polarity of the interpole should always correspond to the polarity of the main magnetic pole toward which the brushes must be moved from the neutral plane in order to improve commutation. Thus, in a generator the brushes are moved forward from the neutral plane and the polarity of the interpole corresponds to the polarity of the magnetic pole toward which the brushes are moved; and in the motor the brushes are moved backward from the neutral plane, which results in the polarity of the interpole for the motor being opposite the polarity of the interpole for the generator, the polarity of the main magnetic poles being the same in each case.

Counter-Electromotive Force.—When the armature of a motor is revolving in the magnetic field of the machine, there is an electromotive force induced in the wires on the surface of the armature, called *conductors,* just the same as there would be if the machine were operated as a generator. Since the relation between the direction of motion of a wire carrying a current when it is placed in a magnetic field and the direction of the magnetic field in the case of a motor is opposite to what it is in the case of a generator, the direction of the current in the wires and the direction of the magnetic field remaining constant, the induced electromotive force in the armature winding of the motor will be just the reverse of what it

is in the case of the generator. This induced electromotive force acts in a direction just opposite to the impressed electromotive force which is producing the current in the armature winding, and, for that reason, it is called a *counter-electromotive force* of the motor. The value of the counter-electromotive force E_c may be calculated by means of the following equation:

$$E_c = \frac{Z \times \phi \times p \times \text{r.p.m.}}{10^8 \times 60 \times a}$$

in which E_c is the counter-electromotive force; Z is the number of conductors on the armature; ϕ is the magnetic flux per pole; p is the number of poles; a is the number of paths through the armature; r.p.m. is the number of revolutions per minute; 10^8 changes absolute units to volts; and 60 changes revolutions per minute to revolutions per second.

Mechanical Output of a Motor.—The output of a motor in foot-pounds per second is equal to the product of the turning effort of the armature, called its *torque*, measured in pound-feet, the speed of the armature in revolutions per second, and 6.2832. Representing the torque by T and the speed by r.p.s., we have the following equation:

$$\text{foot-pounds per second} = T \times \text{r.p.s.} \times 6.2832$$

Since one horsepower is equal to 550 foot-pounds per second, then the output of the motor in horsepower (abbreviated hp.) will be equal to the foot-pounds per second divided by 550, or

$$\text{hp.} = (T \times \text{r.p.s.} \times 6.2832) \div 550 \quad \ldots\ldots \text{(a)}$$

If the speed is measured in revolutions per minute, r.p.m., then

$$\text{hp.} = (T \times \text{r.p.m.} \times 6.2832) \div 33000 \quad ..(b)$$

Example.—Determine the torque in pound-feet exerted by the armature of a motor when the machine is developing 10 horsepower at a speed of 1000 revolutions per minute.

Solution.—Equation (b), as given above, may be rewritten so as to give the value of the torque T in terms of the other quantities as follows:

$$T = \frac{\text{hp.} \times 33000}{\text{r.p.m.} \times 6.2832}$$

Substituting the values in this equation of the horsepower and revolutions per minute given in the problem gives

$$T = \frac{10 \times 33000}{1000 \times 6.2832}$$

$$= 52.5+ \text{ pound-feet}$$

This means there would be a difference in the pull on the driving and slack sides of a belt of 52.5 pounds, if the radius of the pulley over which the belt runs was one foot.

Torque Produced by Armature Current.—The torque produced by the current in the armature of a motor is equal to the combined effects of all of the conductors on the surface of the armature in tending to produce rotation. The product of the total force, in pounds, acting on the conductors and the distance of the conductors from the center of the armature, in feet, gives the value of the torque in pound-feet. The value of the torque may be calculated as follows: The impressed electromotive force E is equal to the sum of the counter-electromotive force E_c and the resistance drop in the armature,

which is equal to the product of the armature current I_a and the resistance of the armature circuit R_a. Putting this relation in the form of an equation gives

$$E = E_c + I_a R_a$$

Multiplying the above equation by I_a gives

$$EI_a = E_c I_a + I_a^2 R_a$$

The term EI_a represents the total power, in watts, supplied to the armature of the motor, and $I_a^2 R_a$ is the power lost in heat in the ohmic resistance of the armature circuit. It follows, therefore, that $E_c I_a$ is the amount of mechanical power developed in the armature in watts. All of this mechanical power is not available at the shaft or pulley, for some of it is used in overcoming friction of the bearings, friction of the brushes on the commutator, windage, and the iron losses in the motor.

The mechanical horsepower P developed in the armature may be expressed in terms of the speed in revolutions per minute, r.p.m., the torque T in pound-feet, and the constants 6.2832, 550, and 60, as follows:

$$P = \frac{6.2832 \times \text{r.p.m.} \times T}{60 \times 550}$$

The mechanical horsepower is also equal to $E_c I_a \div 746$. Placing these two values of the horsepower equal to each other gives

$$\frac{E_c I_a}{746} = \frac{6.2832 \times \text{r.p.m.} \times T}{60 \times 550}$$

Solving this equation for the total torque T developed in the armature gives

$$T = (7.05 \times I_a \times E_c) \div \text{r.p.m.}$$

Substituting the value of E_c gives

$$T = \frac{7.05 \times I_a \times Z \times \theta \times p \times \text{r.p.m.}}{10^8 \times a \times 60 \times \text{r.p.m.}}$$

$$= \frac{.1175 \times I_a \times Z \times \phi \times p}{10^8 \times a}$$

The only quantities in the above equation which may vary during the operation of the motor are the armature current I_a and the magnetic flux per pole ϕ. The conductors Z, the number of poles p, and the number of paths a through the armature remain constant after the machine is constructed.

The total torque of a direct-current motor varies directly as the product of the armature current, the magnetic flux per pole, and a constant whose value depends upon the construction of the motor as indicated above.

Normal Speed of a Motor.—The current in the armature of a motor depends upon the difference between the value of the impressed electromotive force and the counter-electromotive force divided by the resistance of the armature circuit. Representing the impressed electromotive force by E, the counter-electromotive force by E_c, the resistance of the armature circuit by R_a, and the armature current by I_a, then

$$I_a = \frac{E - E_c}{R_a}$$

Since the armature current depends upon the counter-electromotive force, as shown in the above equation, the motor armature will operate at such a speed that the difference between the impressed electromo-

tive force and the counter-electromotive force will produce sufficient current in the armature to produce the required torque in order that the machine may drive its load. Thus, with an increase in load on the motor there will be an increase in torque required, and this increase in torque will mean an increase in armature current if the field strength remains constant, but in order that the current in the armature increase—the resistance of the armature circuit and the impressed electromotive force remaining constant —the value of the counter-electromotive force must decrease. The only factor in the equation giving the value of the counter-electromotive force which can change is the speed, since the field strength or magnetic flux per pole ϕ is supposed to remain constant and the other factors are governed by the construction of the machine and cannot be changed without rebuilding. There will then be a reduction in speed, when the armature current must increase in value in order to take care of an increase in load on the machine.

If the magnetic flux per pole changes at the same time there is a change in armature current, the change in speed with a change in load will be different than when the magnetic flux per pole remains constant. Thus in a series motor the field strength increases with an increase in armature current and, as a result, the speed will have to decrease more in order to reduce the counter-electromotive force to its proper value, than in the case of the shunt motor. The speed characteristics of the different motors are discussed in detail in the next chapter.

Starting of Direct-Current Motors.—There is no counter-electromotive force generated in the armature

winding of a direct-current motor when the armature is stationary; and if the armature were connected directly to the line, a very large current would be produced which would likely injure the motor. The value of the current just at the instant the circuit is closed and before there is any counter-electromotive force generated is equal to the impressed voltage E divided by the resistance of the armature circuit R_a. The resistance of the armature circuit is usually very small and, as a result, there is an excessive current produced. By placing a resistance in series with the armature, the current may be prevented from rising to an excessive value. Now as the armature starts to rotate, due to the torque produced by the current in the armature winding, there will be a counter-electromotive force produced in the winding which opposes the impressed voltage, and the current decreases in value as the speed continues to increase. The speed of the motor will become constant when the current has been reduced to such a value, due to the increase in counter-electromotive force, that the torque produced is just ample to drive the load connected to the motor. Part of the resistance in series with the armature may be removed, however, before the speed has become constant, as the current has decreased, due to the increase in counter-electromotive force. When the resistance is decreased, the current suddenly increases but immediately starts to decrease if the counter-electromotive force continues to increase. The value of the current in the armature circuit of a motor when it is being started may be prevented from exceeding a predetermined value by decreasing the resistance placed in series with the armature at such a rate that the counter-electromotive

force has ample time to increase in value and replace the voltage drop in the series resistance.

A simplified diagram of the connections of a starting resistance is shown in Figure 64. The field circuit of the motor must, of course, be closed when the machine is being started in order that a torque be produced which will cause the armature to rotate and, as a result of the rotation of the armature, there will be a counter-electromotive force generated in the armature winding.

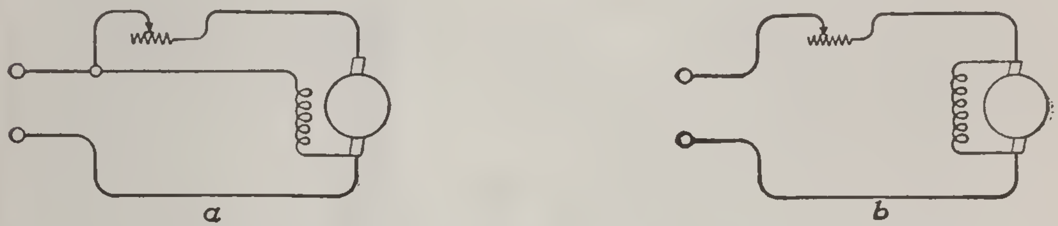


Figure 64.—Connections of Starting Resistance. *a.*—Correct Method. *b.*—Incorrect Method.

Starting Boxes.—If an ordinary resistance similar to the one shown in Figure 64 was used in commercial installations of motors, there would be great danger of burning out the armature winding if, after the motor had stopped, due to the circuit to which it was connected becoming dead, the circuit should again become alive; for in that case the full line pressure would be connected directly across the low-resistance armature circuit which would result in a very large current. For this reason most starting resistances or rheostats are provided with what is called a *no-voltage release* which automatically causes the starting handle of the rheostat to be restored to its starting position when the line to which the motor is connected becomes dead. Very frequently these starting rheostats are equipped with what is called an *overload*

release which serves to disconnect the motor from the circuit if the current becomes excessive for any reason or exceeds the value for which the overload release is set to operate.

In some cases a field-regulating resistance is combined with a starting rheostat. Such a rheostat, manufactured by the Cutler-Hammer Manufacturing Company, is shown in Figure 65. The movable arm consists of two parts and their outer ends move over

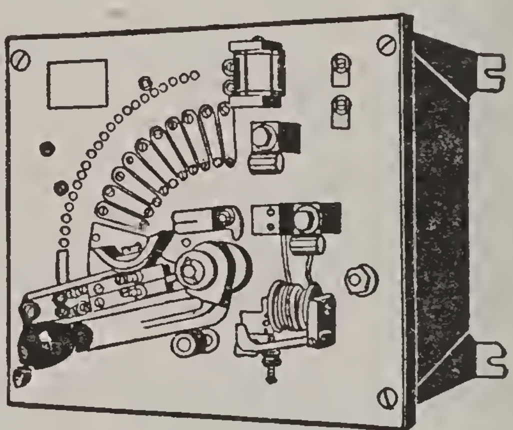


Figure 65.—Motor Starting Box with No-voltage and Overload Release.

separate sets of contacts. When the motor is being started, both parts of the arm are first moved into a vertical position and the lower portion is held in that position by the no-voltage release magnet, while the upper part of the arm may be moved back over the upper row of contacts which are connected to the field-regulating resistance.

Starting rheostats used in connection with series motors on street cars are not provided with a no-voltage release as the motorman is supposed to return the controller handle to the starting position when the line becomes dead. An overload on the motors

is prevented by means of a circuit-breaker. In some cases the motorman must hold the controller hand in the various positions against the action of a spring which will restore the handle to its starting position should the motorman happen to let go the handle.

CHAPTER VII

SPEED CONTROL, OPERATING CHARACTERISTICS, AND TESTING OF DIRECT-CURRENT MOTORS

Methods of Regulating the Speed of Direct-Current Motors.—The speed of a direct-current motor may be regulated by any one, or certain combinations of the following methods:

(A) Change in magnetic flux per pole
(B) Change in voltage impressed upon the armature terminals
(C) Change in brush position
(D) Series-parallel connections of motors, as in railway work

Regulating Speed by Change in Magnetic Flux.—There are two distinct methods used in changing the magnetic flux per pole in a motor:

(a) By changing the ampere turns producing the magnetic flux
(b) By changing the reluctance of the magnetic circuit

(a) The current in the field winding of a shunt motor is equal to the voltage acting on the field circuit divided by the resistance of the field circuit. If a suitable resistance be connected in series with the shunt-field winding, as shown in Figure 66, the current in the circuit may be varied from a very low value to be a maximum value equal to the impressed voltage divided by the resistance of the field winding alone.

The current in the field winding of a series motor varies as the armature current, and the two are usu-

ally equal in value. A variable resistance, however, may be connected about the series, as shown in Figure 67, and the portion of the total current which passes through the series field varied by adjusting the variable resistance. In some cases the field coils are so arranged that they may be connected in series

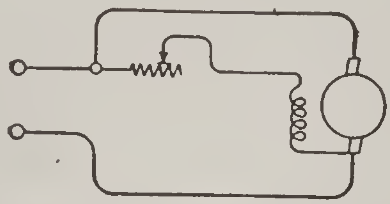


Figure 66.—Connection of Field Rheostat in Field of Shunt Motor.

in parallel or in a combination of series and parallel by means of a suitable controller, which results in each coil carrying a different part of the total current for the different connections.

The field strength of the compound motor depends upon the combined action of the shunt and the series

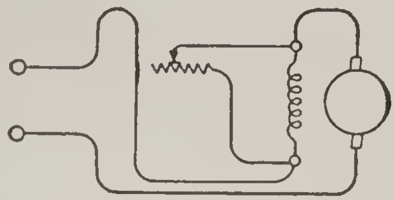


Figure 67.—Connection of Variable Resistance in Parallel with Field of Series Motor.

windings. The current in either of these windings may be varied as described above, and, as a result, there will be a change in the strength of the magnetic field or flux per pole.

If the flux per pole in a direct-current motor be decreased in value, there will be an increase in speed for the following reason. The decrease in flux per

pole results in a decrease in counter-electromotive force and the current in the armature immediately increases, which results in a greater torque being produced than is required to drive the load and the speed of the motor increases. The increase in speed causes the counter-electromotive force to increase, which reduces the value of the current; and when the current has decreased to such a value that the torque being developed is equal to that required to drive the load, the speed will become constant. The change in the flux per pole resulting from a change in the current in the field winding will depend upon the degree to which the iron of the magnetic circuit of the motor is saturated. If the magnetic circuit is being worked at a point well up on the magnetization curve, there must be a relatively large change in field current to produce a comparatively small change in magnetic flux.

There is a limit, however, to the amount you can weaken the magnetic field of a motor as the armature reaction, due to a given armature current, increases with a decrease in field strength, which results in poor commutation. The effect of armature reaction can be reduced in a number of different ways, as explained in Chapter VI, but the results obtained when interpoles are used are more satisfactory than by any of the other methods. Without interpoles, it is impossible to vary the speed of a motor whose normal speed is about 1000 revolutions per minute more than two or three hundred revolutions by changing the field strength without trouble due to sparking, while the minimum and maximum speeds of an interpole motor may be in the ratio of one to six without serious sparking.

(b) The magnetic flux per pole may be reduced by increasing the reluctance of the magnetic circuit, there being no change in the ampere turns per pole. This is accomplished in the case of a motor manufactured by the Stow Manufacturing Company, in the following way: The field cores are hollow and provided with movable iron cores. The movable iron cores are mechanically connected so that their position within the hollow cores can be adjusted by means of a hand wheel on top of the machine. By moving them toward or away from the pole pieces, there will be a decrease or increase in the reluctance of the magnetic flux per pole which will produce a change in the speed.

In the Lincoln adjustable speed motor, the armature core is tapered and also the field bore, so that as the armature is moved endwise by means of a special mechanical device, the length of the air gap is increased or decreased and the magnetic fiux per pole changed. In small motors of this type the ratio of the maximum and the minimum speeds may be as much as ten to one.

Controlling Motor Speed by Varying Voltage Impressed upon the Armature Terminals.—The voltage impressed upon the terminals of the motor may be varied by any one of the following methods:

(a) By placing a resistance in series with the armature
(b) By operating the motor on a multi-voltage system
(c) By varying the voltage of the generator supplying current to the motor

(a) If a rheostat be placed in series with the armature of a motor, as shown in Figure 68, the voltage across the armature terminals may be varied by changing the resistance of the rheostat. A change

in impressed voltage on the armature will mean a change in speed, because there will be a change in the value of the counter-electromotive force required.

This method of controlling the speed is not at all efficient on account of the loss in the series resistance.

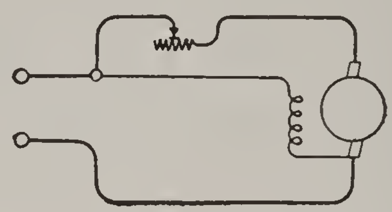


Figure 68.—Resistance in Series with Armature Circuit.

The voltage impressed upon the armature will change with a change in armature current, which results in a greater change in speed with change in load than would occur if the voltage over the armature remained constant.

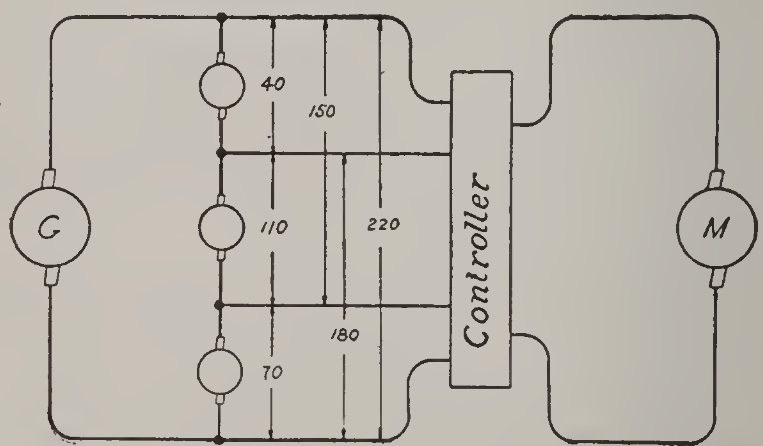


Figure 69.—Multi-voltage Method of Speed Control.

(b) In the multi-voltage method of speed control, there are several different voltages available from which the motor may be operated. Thus, as shown in Figure 69, the voltage between the main lines is subdivided by means of a balancer set which makes it possible to impress upon the armature a

number of different voltages. The motor will have a definite speed for each of these voltages and it will be practically constant for all loads when the controller resistance in series with the armature is all out of circuit. The shunt field winding is usually connected permanently to the main line, and the field strength remains practically constant for all connections of the armature. The controller used in changing the armature connections is quite similar to an ordinary railway motor controller.

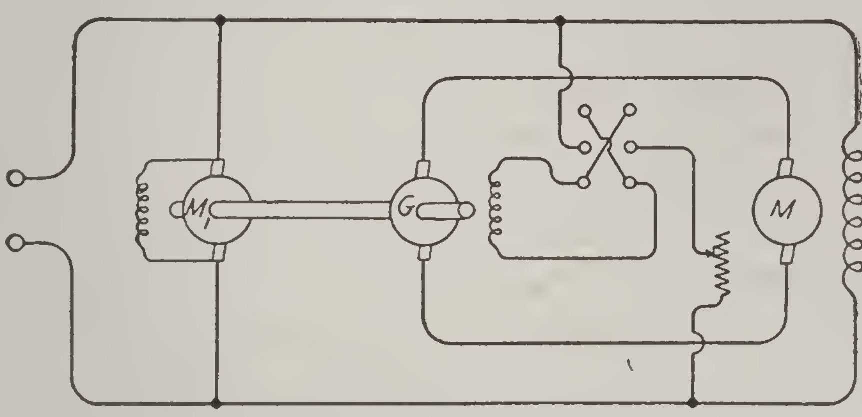


Figure 70.—Ward-Leonard System of Speed Control.

It is possible, with the arrangement indicated in Figure 69, to impress six different voltages upon the armature of the motor, namely, 40, 70, 110, 150, 180, or 220 volts, giving six different speeds. Speeds intermediate between those given by the above voltages may be obtained by varying the strength of the magnetic field. This system is extensively used in operating machine tools, but it has the disadvantage of requiring quite a large investment in the balancer and extra copper required in the distributing circuits.

(c) The speed of a motor may be controlled by varying the voltage of the generator supplying current to the motor, as shown in Figure 70, which

shows diagrammatically what is known as the Ward-Leonard system. The motor M, whose speed is to be controlled, is separately excited from the main circuit and its armature is directly connected to the terminals of the armature of an auxiliary generator G. The generator G is driven by a shunt motor M_1, which takes its power from the main line. It is not necessary that a motor be used in driving the generator G, as any other form of prime mover may be used. The field of the generator G is connected to the main line through a reversing switch, and a rheostat is in series by means of which the voltage may be adjusted from zero to a maximum value in either direction. With this combination, it is possible to get a very uniform variation in the voltage impressed upon the motor and the operation will be very satisfactory. This method is especially useful where very uniform gradation of speed in either direction is required, as in the operation of the turrets on battleships, etc., but it is expensive because of the additional equipment.

Controlling the Speed of a Motor by Varying the Position of the Brushes.—If the brushes of a direct-current motor be moved from the neutral plane of the magnetic field, there will be a change in speed for the following reasons. The counter-electromotive force between the brushes of a motor is maximum when the brushes are in the neutral plane, because the electromotive forces induced in all the conductors in series in the various paths through the armature winding are all acting in the same direction. If the position of the brushes be changed, assuming the magnetic flux per pole and the speed remains constant, then the counter-electromotive force between the

brushes will be reduced and the current in the armatuer winding will be increased, which causes an increase in torque and, hence, an increase in speed. The magnetic flux pole and the position of the neutral plane do not remain constant when the position of the brushes is changed, even though the armature current remains constant, as there is a change in the effect of armature reaction. If the brushes are moved back of the neutral plane, there is an increase in the demagnetizing ampere turns and a decrease in the cross-magnetizing ampere turns, assuming the armature current does not change in value, causing a decrease in magnetic flux per pole and also a decrease in the distortion of the magnetic field. When the brushes are moved forward of the neutral plane, there will be a decrease in the demagnetizing ampere turns on the armature and an increase in the cross-magnetizing ampere turns, assuming the armature current does not change in value, causing an increase in magnetic flux per pole and also an increase in distortion of the magnetic field. An increase in magnetic flux per pole alone means a decrease in speed or a decrease in magnetic flux per pole an increase in speed, likewise, a change in brush position alone means an increase in speed as they are moved from the neutral plane. It is readily seen that the change in speed resulting from a change in brush position will depend upon the change in magnetic flux per pole caused by the brushes being changed and also the relative relation of the brush position and the neutral plane before and after the change is made. Usually there is an increase in speed as the brushes are moved in either direction from their normal position, but in some cases there

may be first a decrease and then an increase in speed when the brushes are moved in advance of the neutral plane, especially if the motor is carrying quite a large load and the brushes are moved from a position determined when the motor was operating without load. This method of varying the speed of a motor is not at all practical, as excessive sparking usually results when the brushes are moved very far from their proper position. In the case of the interpole motor the brushes must always be placed in a definite position on the commutator in order that the parts of the winding undergoing commutation may be in the proper position with respect to the interpoles. This position is usually such that the motor may be operated in either direction equally well.

The brushes, in the case of an ordinary motor, may be placed in the neutral plane by moving them back and forth, at the same time noting the changes in speed, and the position giving minimum speed will correspond to the neutral plane, no load on the motor. The brushes are usually moved back a slight amount of the minimum speed position for no load, so that their position with respect to the neutral plane will be nearer correct under load conditions than it would be if they were not moved.

Control of Motor Speed by Series-Parallel Connections.—The control of motors by the series- parallel method depends upon a change in voltage over the armatures of the different motors which is produced by a change in connections of the motors together with a resistance arranged so it can be connected in circuit and varied in value. This method of control is confined almost entirely to series railway motors where there are two or more on each car.

In the case of cars having two-motor equipment, the two motors and the starting resistance are all connected directly in series when the starting handle is thrown to the first position. As the starting handle is moved from the first position to the second, and

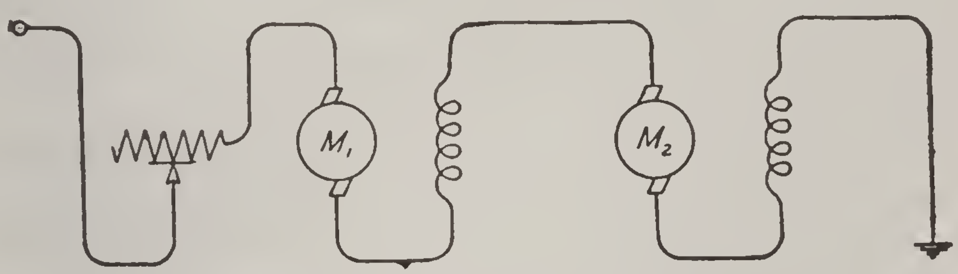


Figure 71.—Motors in Series.

so on, the resistance in circuit is reduced in value until the two motors are connected directly in series with the full voltage across the combination. A further movement of the starting handle connects the two motors in parallel and a resistance in series

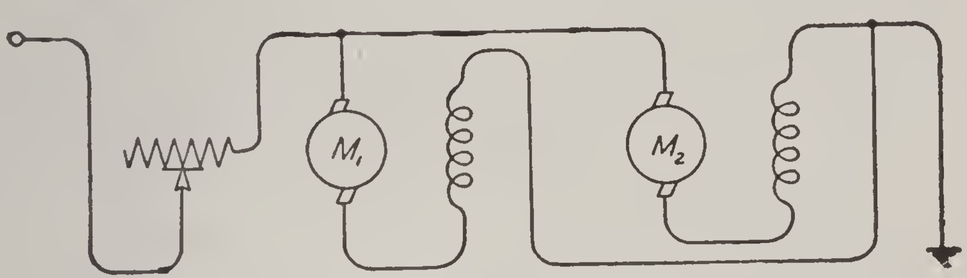


Figure 72.—Motors in Parallel.

with them; this resistance is then cut out as the starting handle is moved on toward its last position when the motors are in parallel with full voltage impressed upon each. A good idea of the operation of a two-motor equipment may be obtained by reference to Figures 71 and 72. In Figure 71 the motors are in series and in Figure 72 they are in parallel.

When four-motor equipments are used, the motors are usually connected in parallel in pairs and the two pairs are then connected in series-parallel just as though each pair were a single motor. The series-parallel method of control is more economical than if each motor had its own individual starting resistance, or if all the motors were in parallel and provided with a single starting resistance.

The successive changes in the starting resistance and the change in the connections of the motors are accomplished by means of a device called a *controller*. The two positions of the controller in which the motors are directly in series or directly in parallel, without any resistance in circuit in either case, are called *running points,* because in these positions there is no loss in the starting resistance. All other positions of the controller, except those where the change from series to parallel connection takes place, are called *resistance points.*

There are a number of different types of railway motor controllers on the market and they perform their functions in a little different manner. Thus, type *R* controllers are those in which rheostats are used without any series-parallel arrangement. This type of controller is generally used with single-motor railway equipments, or for cranes and hoists. Type *K* controllers are for series-parallel control of two or more series motors and are so constructed that the power circuit is not broken when the change is made from series to parallel connection. Type *L* controllers are also for series-parallel control of two or more series motors and are so constructed that the power circuit is broken when the change is made from series to parallel connection. Type *B* controllers

have the customary power circuit connections and, in addition, make use of the motors as generators in operating magnetic brakes of the axle or track type.

All of the controllers given above, with the exception of certain *R* types, are provided with two handles—one for the control of the resistance and motor connections and the other for the reversal of the direction of the motion of the car. These two handles are usually mechanically interconnected in such a way that the reversing handle cannot be moved unless the main control handle is in the "off" position, and likewise the main handle cannot be moved unless the reversing handle is in either the forward, or reverse, position.

The controllers described thus far will work in the case of a single car, or a motor car and trailer, but where several motor cars and trailers are to be operated as a train, a multiple-unit type of control, such as the type *M*, must be used. The controller in this case carries only a small auxiliary current independent of the current in the motor and this current operates electromagnets which, in turn, operate devices called *contactors* that control the main current. The current operating the electromagnets of the contactors may be controlled from any number of different positions, depending upon the number of controllers connected to the circuit. This control circuit is continuous through the different cars forming the train by means of a flexible multiple conductor connection between the different cars. This type of control is frequently used on single cars, as it eliminates the necessity of carrying the heavy motor currents through the controller in the motorman's cab.

Operating Characteristic of Direct-Current Motors.—There are three principal classes of service in the commercial application of motors and these classes may be characterized as follows:

(a) Constant speed
(b) Adjustable speed
(c) Variable speed

(a) Constant-speed motors are those which maintain a practically constant speed at all loads, when operated on a constant-voltage circuit. Motors of this kind are used in driving machinery whose speed is to remain practically constant at all times, as line shafting.

(b) Adjustable-speed motors are those whose speed can be fixed at any one of a large number of values between a minimum and maximum value, and, after such an adjustment is made, the speed will remain practically constant for all loads not exceeding the capacity of the machine, the impressed voltage remaining constant. Motors of this kind are used, for example, for individual drives for machine tools.

(c) Variable speed motors are those whose speed changes, due to a change in load without any adjustment when operating with a constant impressed voltage. Motors of this kind are used where it is desirable to have their speed decrease as the load they are operating increases, as in street-railway work, hoisting machinery, and rolling mills.

In order to completely understand the operation of the different types of direct-current motors, it is necessary to get a mental picture of the relation between speed, torque, and load current. These relations determine what are called the operating or com-

mercial characteristics and they will be discussed in the following sections:

Characteristics of the Shunt Motor.—When the shunt motor is operated with a constant impressed voltage and constant resistance in the field circuit, its speed will usually decrease with an increase in load or armature current, as shown in Figure 73. If the decrease in field strength, due to armature reac-

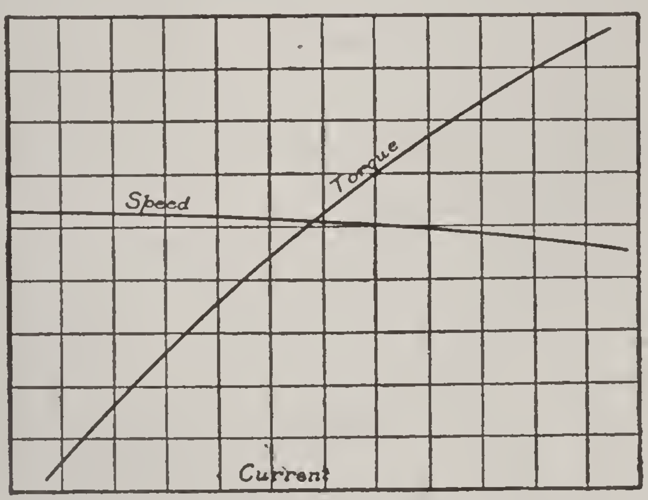


Figure 73.—Characteristics of Shunt Motor.

tion, causes the required decrease in counter-electromotive force as the armature current increases, then the speed will remain practically constant. There will be a smaller decrease in speed in a shunt motor having a low armature resistance than in the case of one having a relatively high armature resistance.

The torque of a shunt-motor increases with an increase in armature current and would vary directly as the armature current if the field strength of the machine and the position of the brushes with respect to the neutral plane of the field remained constant. The total torque in the case of a shunt motor is

related to the armature current as shown in Figure 73.

Characteristics of the Series Motor.—The speed of a series motor decreases with an increase in armature current, which causes an increase in magnetic flux per pole and also a decrease in the required counter-electromotive force. The speed is a maximum at no load and theoretically it would be infinite. The relation of speed to armature current for the series motor is shown in Figure 74.

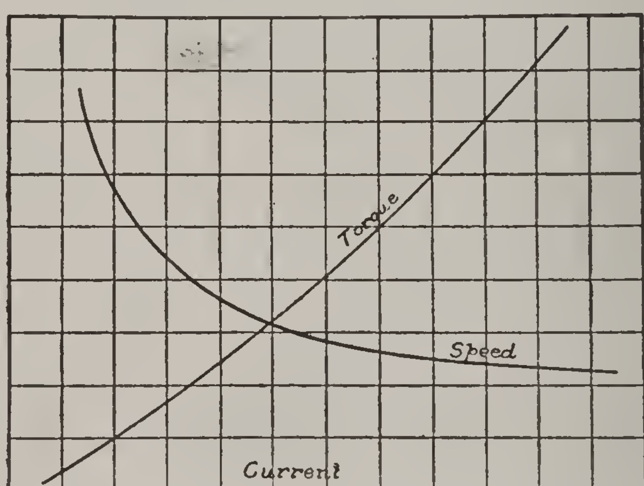


Figure 74.—Characteristics of Series Motor.

The torque of a series motor increases more rapidly with an increase in armature current than in the case of the shunt motor, because the magnetic flux per pole is increasing at the same time the armature current is increasing. If the magnetic flux per pole increased directly as the armature current, then the torque would vary as the square of the armature current, since the torque is proportional to the product of the magnetic flux per pole and the armature current. The magnetic flux per pole, however, does not increase as rapidly as the armature current, due

to the magnetic circuit becoming saturated, and, hence, the torque increases less and less rapidly as the armature current increases in value. The relation of the total torque to the armature current for the series motor is shown in Figure 74.

Characteristics of the Compound Motor.—When the shunt and series field windings of a compound motor are connected so that their magnetizing effects both act in the same direction, it is called a *cumulative*

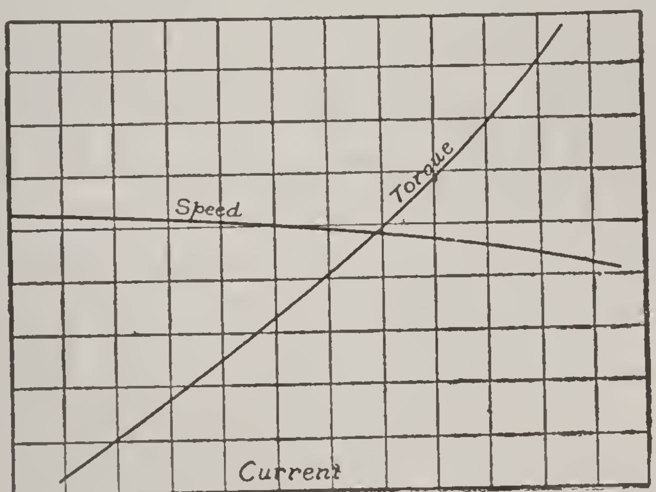


Figure 75.—Characteristics of Cumulative Compound Motor.

compound motor; and if the magnetizing effects of the two field windings oppose each other, it is called a *differential compound motor.*

The speed of a cumulative compound motor decreases more rapidly with an increase in armature current than in the case of the shunt motor, because the magnetic flux per pole is increasing with an increase in armature current which passes through the series field winding. The relation of speed to armature current for the cumulative compound motor is shown in Figure 75.

The torque of a cumulative compound motor in

creases more rapidly with an increase in the armature current than in the case of the shunt motor, because the magnetic flux per pole is increasing, due to the acting of the armature current in the series field winding. The relation of torque to armature current for the cumulative compound motor is shown in Figure 75.

The speed of a differential compound motor does not decrease as much with an increase in armature

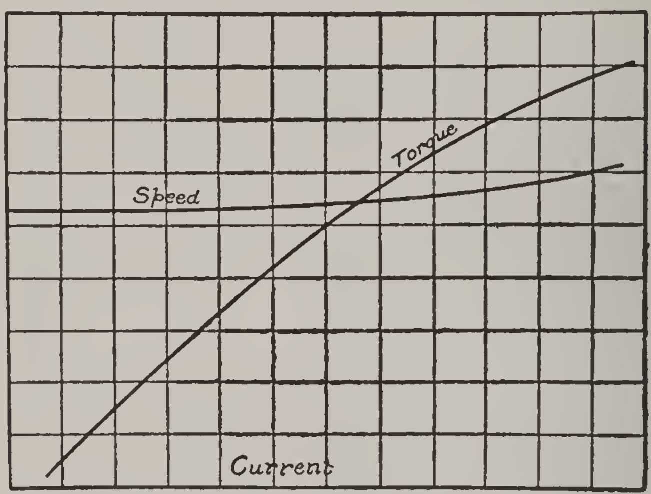


Figure 76.—Characteristics of Differential Compound Motor.

current as in the case of the shunt motor, because the magnetic flux per pole is decreased, due to the action of the armature current in the series field winding. The speed may remain practically constant, it may decrease a slight amount, or it may increase with an increase in armature current, depending upon the effect of the series field winding in changing the value of the magnetic flux per pole. The relation of speed to armature current for a differential compound motor is shown in Figure 76.

The torque of a differential compound motor does not increase as rapidly with an increase in the arma-

ture current as in the case of the simple shunt motor, because the magnetic flux per pole is decreased, due to the action of the current in the series field winding. The relation of torque to armature current for the differential compound motor is shown in Figure 76.

The differential compound motor is seldom used in practice for the reason that the slightly drooping speed characteristic for the simple shunt motor meets practically all of the requirements of constant speed. Such motors are likely to start up in the wrong direction when the starting handle of the starting rheostat is turned to the first notch, because the shunt does not build up to its maximum value instantly and, hence, the direction of the magnetic flux will be governed by the current in the series field. When the shunt current has had time to build up, the magnetic flux per pole will be reversed and, hence, the direction of rotation of the armature.

Losses in Direct-Current Motors.—The losses in motors may be divided into two main groups:

(a) Electrical losses
(b) Stray-power losses

(a) The electrical losses occur in any part of the motor carrying a current, and the value of this loss, in watts, for any circuit is equal to the current in the circuit squared times the resistance of the circuit. Thus, if the current in the armature be represented by I_a and the resistance of the armature by R_a, then the electrical loss in the armature will be given by the following equation:

$$\text{electrical loss in armature} = I_a^2 R_a \text{ watts}$$

The electrical loss in any other part of the motor may be calculated as indicated above.

(b) The stray-power losses consist of:

(1) Hysteresis and eddy-current losses, chiefly in the armature, called iron losses.
(2) Friction loss at the bearings and the brushes, and air friction, or windage, as it is called, due to the fan-like action of the different parts.

The stray-power losses cannot be calculated with the same degree of accuracy as the electrical losses; but they can, however, be quite accurately determined by experiment for a given machine.

Efficiencies of a Direct-Current Motor.—There are three efficiencies for a direct-current motor, namely,

(a) Efficiency of conversion
(b) Mechanical efficiency
(c) Commercial efficiency

(a) The efficiency of conversion is equal to one hundred times the ratio of the total mechanical power developed to the total electrical power supplied. The total mechanical power developed in a motor is equal to the input minus the electrical losses, or to the output plus the stray-power losses. The input to the motor in watts is equal to the product of the voltage E impressed upon the armature terminals and the total current supplied to the motor, or

$$\text{input} = E \times I \text{ watts}$$

The power output of the motor in watts is equal to the horsepower (hp.) delivered by the motor multiplied by 746, or

$$\text{output} = \text{hp.} \times 746 \text{ watts}$$

$$\text{total power developed} = (E \times I) - \text{electrical losses}$$

or

$$= (\text{hp.} \times 746) + \text{stray-power losses}$$

$$\text{efficiency of conversion} = \frac{EI - \text{electrical losses}}{E \times I} \times 100$$

or

$$= \frac{746 \times \text{hp.} + \text{stray-power losses}}{E \times I} \times 100$$

(b) The mechanical efficiency of a motor is equal to one hundred times the ratio between the output of the motor and the total mechanical power developed.

$$\text{mechanical efficiency} = \frac{746 \times \text{hp.}}{746\,\text{hp.} + \text{stray-power loss}} \times 100$$

or

$$= \frac{746 \times \text{hp.}}{E \times I - \text{electrical losses}} \times 100$$

(c) The commercial efficiency of a motor is equal to one hundred times the ratio of the output to the input.

$$\text{commercial efficiency} = \frac{746 \times \text{hp.}}{E \times I} \times 100$$

The commercial efficiency is the most important of the three, as it includes all the losses in the machine and is of more interest to the purchaser than either of the other efficiencies.

Determining the Commercial Efficiency by Prony Brake.—The commercial efficiency of a motor may be determined by measuring the electrical input by means of a voltmeter and ammeter or by means of a wattmeter, and at the same time measuring the mechanical output. The mechanical output of the motor

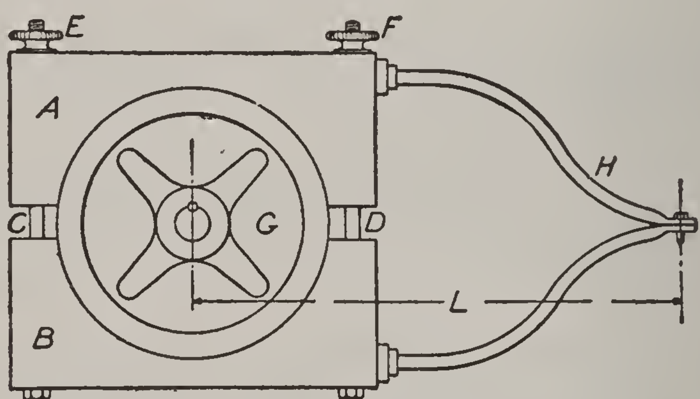


Figure 77.—Prony Brake.

may be determined by means of a Prony brake. The construction and operation of this brake can best be explained by reference to Figure 77. The brake proper consists of two parts *A* and *B*, that are held together by two bolts, *C* and *D*. The bolts are provided with two hand wheels *E* and *F* by means of which the pressure of the two parts of the brake *A* and *B* upon the pulley *G* can be varied. An arm *H* is attached to the brake and extends out to one side at right angles to the shaft upon which the pulley *G* is mounted. When the brake is in use, the outer end of the arm *H* rests upon the platform of a pair of scales or it is hung from a spring balance. The torque

produced by the armature driving the pulley G, in pound-feet, is equal to the net reading of the scales at the end of the arm H, in pounds, multiplied by the horizontal distance L, in feet, from the center of the shaft to the point where the end of the arm H rests upon the scales. The net scale reading is obtained by subtracting from the scale readings for the different loads the scale reading when the pulley is not revolving. Representing the net scale reading by W, then

$$T = W \times L \text{ pound-feet}$$

and the output in horsepower will be equal to

$$\text{hp.} = \frac{6.2832 \times T \times \text{r.p.m.}}{33000}$$

$$= \frac{6.2832 \times W \times L \times \text{r.p.m.}}{33000}$$

Substituting this value of the output in horsepower in the equation for commercial efficiency gives

$$\text{commercial efficiency} = \frac{746 \times 6.2832 \times W \times L \times \text{r.p.m.}}{E \times I \times 33000} \times 100$$

$$= \frac{14.203 \times W \times L \times \text{r.p.m.}}{E \times I}$$

Example.—In testing a direct-current motor by means of a Prony brake, the net scale reading was 55 pounds, the lever arm of the brake was 2 feet, and the motor was running at a speed of 1000 r.p.m. What was its commercial efficiency if the input was 80 amperes at 220 volts?

Solution.—Substituting directly in the equation for commercial efficiency gives

$$\text{commercial efficiency} = \frac{14.203 \times 55 \times 2 \times 1000}{220 \times 80}$$

$$= 88.7 + \text{per cent}$$

CHAPTER VIII

CARE AND OPERATION OF DIRECT-CURRENT MOTORS AND DIRECT-CURRENT MOTOR TROUBLES

The following instructions relative to the care and operation of direct-current machines are reproduced mainly from the "General Rules" of the Westinghouse Electric and Manufacturing Company, Pittsburgh, Pennsylvania.

General Rules.—(1) Leave all switches open when machine is not running.

(2) At all times keep the generator or motor clean and free from oil and dust, especially from copper or carbon dust. The finest machines and the most expensive plant may be shut down by accident if they do not have protection and care. The insulation must be kept clean and dry. Oil and dirt in the insulation are as much out of place as grit or sand in a cylinder or bearing. In a direct-connected unit, oil may splash from the driving machine, or work along the shaft to the insulation and cause a burn-out if the attendant has not provided the necessary protection. With high voltage machines a small accumulation of dust on the windings may be the cause of serious burn-out. In stations of sufficient size to warrant the expense, it is advisable to install an air pump with a piping system so distributed that a short section of hose will enable the attendant to reach all parts of the winding on any machine to blow out the dust. The pressure used

in such service should not exceed 25 pounds per square inch, as a high pressure may lift the insulation wrappings on the windings and blow dust inside the coils. Always allow the accumulation of water in the pipes to be blown out before turning the air blast on the machine.

(3) Keep small pieces of iron, and bolts, and tools away from the frame. Any such fragment attracted to the pole of a field magnet may jam between the armature and the pole and cause serious damage.

(4) Occasionally give the machine a thorough inspection. The higher the voltage of the generator or motor, the oftener this should be done.

Brushes.—The position of the brushes on a direct-current machine should be on, or near, the no-load neutral point of the commutator. The no-load neutral point on all standard machines is in line with the center of the pole. Generators should have the brushes set a little in advance of this neutral point. In other words, the brushes of the generator should be given a slight "forward lead" in the direction of rotation of the armature. Motor brushes should be set somewhat back of the neutral point. The "backward lead" in this case is approximately equal to the forward lead on generators. The exact position in either case is that which gives the best commutation at normal voltage for all loads. In no case should the brushes be set so far from the neutral point that it will cause dangerous sparking at no-load.

The ends of all brushes should be fitted to the commutator so that they make good contact over their entire bearing face. This can be most easily accomplished after the brush holders have been adjusted

and the brushes inserted. Lift a set of brushes sufficiently to permit a sheet of sand-paper to be inserted. Draw the sand-paper back and forth under the brushes in the direction of rotation, being careful to keep the ends of the paper as close to the commutator surface as possible and thus avoid rounding the edges of the brushes. It will be found that by this means a satisfactory contact is quickly secured, each set of brushes being similarly treated in turn. If the brushes are copper plated, their edges should be slightly beveled, so that the copper does not come in contact with the commutator.

Commutator.—The commutator should be kept smooth by the occasional use of No. 00 sand-paper. A small quantity of high grade light body oil should be used as a lubricant. The lubricant should be applied to high-voltage generators by aid of a piece of cloth attached to the end of a dry stick. If the commutator gets "out of true" it should be turned down.

Sparking.—Sparking of the brushes may be due to any one of the following causes:

(a) The machine may be overloaded.
(b) The brushes may not be set exactly at the point of commutation. A position can always be found where there is no perceptible sparking, and at this point the brushes should be set and secured.
(c) The brushes may be wedged in the holders.
(d) The brushes may not be fitted to the circumference of the commutator.
(e) The brushes may not bear on the commutator with sufficient pressure.
(f) The brushes may be burnt on the ends.
(g) The commutator may be rough; if so, it should be smoothed off.

(h) A commutator bar may be loose, or may project above the others.
(i) The commutator may be dirty, oily, or worn out.
(j) Unsuitable carbon in the brushes.

These are the more common causes, but sparking may be due to an open circuit or loose connection in the armature. This trouble is indicated by a bright spark which appears to pass completely around the commutator and may be recognized by the scarring of the commutator at the point of open circuit. If a lead from the armature winding to the commutator becomes loose or broken, it will draw a bright spark as the break passes the brush position. This trouble can be readily located, as the insulation on each side of the disconnected bar will be more or less pitted.

The commutator should run smoothly and true, with a dark, glossy surface.

Heating of Field Coils.—Heating of field coils may develop from any of the following causes:

(a) Too low speed.
(b) Too high voltage.
(c) Too great forward or backward lead of brushes.
(d) Partial short circuit of one coil.
(e) Overload.

Heating of Armature.—Heating of the armature may develop from any of the following causes:

(a) Too great a load.
(b) Partial short-circuit of two coils will heat the two particular coils affected.
(c) Short circuits or grounds on armature, or commutator.

Heating of Commutator.—Heating of the commutator may develop from any of the following causes:

(a) Overload.
(b) Sparking at the brushes.
(c) Too high brush pressure.
(d) Lack of lubrication on commutator.

Bearings.—Watch the bearings carefully from the time the machine is first started until the bearings are warmed up, then note the oil level. The expansion of the oil due to heat and foaming raises the level considerably during that time. The oil should be renewed about once in six months, or oftener if it becomes dirty or causes the bearings to heat.

The bearings must be kept clean and free from dirt. They should be examined frequently to see that the oil supply is properly maintained and that the oil rings do not stick. Use only the best quality of oil. New oil should be run through a strainer if it appears to contain any foreign substances. If the oil is used a second time it should first be filtered and, if warm, allowed to cool.

If a bearing becomes hot, first feed heavy lubricant copiously, loosen the nuts on the bearing cap, and then, if the machine is belt connected, slacken the belt. If no relief is afforded by these means, shut down, keeping the machine running slowly until the shaft is cool, in order that the bearing may not "freeze." Renew the oil supply before starting again. A new machine should always be run at a slow speed for an hour or so in order to see that it operates properly. The bearings should be inspected at regular intervals to insure that they always remain in good condition. The higher the speed, the more care should be taken in this regard.

A warm bearing, or "hot box," is probably due to one of the following causes:

(a) Excessive belt tension.
(b) Failure of the oil rings to revolve with the shaft.
(c) Rough bearing surface.
(d) Improper lining up of bearings or fitting of the journal boxes.
(e) Bent shaft.
(f) Use of poor grade or dirty oil.
(g) End thrust, due to improper leveling. A bearing may become warm because of excessive pressure exerted by the shoulder of the shaft against the side of the bearing.
(h) Bolts in the bearing cap may be too tight.
(i) End thrust, due to magnetic pull, rotating part being "sucked" into the field because it extends beyond the field poles further at one end than the other.
(j) Excessive side pull, because the rotating part is out of center.

Starting Constant-Speed Motors, Shunt or Compound.—(1) Examine the oil level in each bearing and see that the oil rings are in good operating condition. Inspect all connections for loose screws or wires.

(2) See that bearings are well supplied with a good lubricating oil and that oil rings are free to turn.

(3) Make sure that the lever arm of the starting box or controller is in the "off" position.

(4) Close the main switch, or circuit breaker.

(5) Close field switch.

(6) Move lever arm of starting box or controller to the running position, pausing long enough on each notch to allow the motor to come up to the speed of that notch.

(7) If using a controller, throw the short-circuiting switch and move controller handle back to the starting position. If using a starting box, the lever arm should remain in the running position.

To Shut Down Constant-Speed Motors.—(1) Open the main switch or circuit breaker.

(2) After the motor has come to rest, see that the lever arm of the starting box has returned to its original position.

(3) Open the field switches.

(4) Clean the machine thoroughly and put in order for next run.

Starting Variable-Speed Motors.—(1) Examine shunt field rheostat, and see that all resistance is cut out.

(2) Follow all directions given under "Constant-Speed Motors."

(3) After motor is running on full line voltage, gradually cut in resistance in the shunt field rheostat until the motor is up to the desired speed.

To Shut Down Variable-Speed Motors.—(1) Gradually cut out the resistance in the shunt field rheostat until the machine is running on a full field.

(2) Follow directions given under "To Shut Down Constant-Speed Motors."

Starting Series Motors.—(1) Follow same instructions as those given for "Starting Constant-Speed Motors," except there is no field switch to close.

To Shut Down Series Motors.—(1) Open main switch or circuit-breaker.

(2) Examine machine carefully, wipe off all dirt or oil, and put in good shape for next run.

Belts.—The belt on a belt-connected machine should be tight enough to run slowly without slipping, but the tension should not be too great or the bearings will heat. Belts should run with, not against, the inside lapping, and the joints should be dressed

smooth so that there will be no jarring as it passes over the pulley.

The crowns of driving and driven pulleys should be alike, as "wobbling" of belts is often caused by pulleys having unlike crowns. If this is caused by bad joints, they should be broken, and cemented over again.

A wave motion or flapping is usually caused by slippage between the belt and the pulley, resulting from loose belt, grease spots, etc. It may, however, be a warning of an excessive overload. This fault may sometimes be corrected by increasing the tension, but a better remedy is to clean the belt. A back-and-forth movement of the pulley is caused by unequal stretching of the edges of the belt. If this does not cure itself shortly, examine the joints. If they are evenly made, and remain so, the belt is bad, and should be discarded.

Static Sparks from Belts.—It sometimes occurs on belted machines, especially in dry weather, that charges of static electricity accumulate on the belt, which may be of sufficiently high potential to cause discharges to ground. If the frame of the machine is not grounded, these charges may jump to the armature or field winding, and thence to the ground, puncturing the insulation. The belt and frame may be discharged by placing a number of sharp metal points, which are carefully grounded, close to the belt at a point near the motor pulley. If the field frame is grounded, there should be no danger to the insulation.

Refusal of Motor to Start.—There are many causes for this trouble, among which may be mentioned the following:

(a) There may be no current on the line. This can be tested at the switch.

(b) Poor contact of brushes or wrong position of brushes. Brushes should be at points diametrically opposite each other.

(c) On series motor there may be an open circuit in armature or fields. If the motor is shunt or compound-wound, an open circuit in the armature may be the cause.

(d) If, upon starting, a fuse burns out, it may be caused by:

(e) Too fast manipulation of the rheostat arm. Usually from 20 to 30 seconds of time are required for the safe starting of a motor.

(f) The motor may be stuck fast in some way, or it may be overloaded.

(g) The motor connections may be wrong.

(h) The field circuit may be open, thus preventing the armature from generating the required counter-electromotive force.

(i) The supply voltage may be higher than the motor was designed for.

(j) There may be a short-circuit in the armature or in the field winding. In a two-wire system a short-circuit may be caused by two grounds. In a three-wire system with grounded neutral, one ground will cause a short-circuit.

(k) Field density light; due probably to short-circuit of part of the coils, or to grounded wires. Indicated by a portion of the field being heated above normal temperature.

(l) The fuses may be too small to carry the required current, or the contacts may be loose, or require cleaning.

Speed of Motor Too Slow.—Caused by:

(a) Too great field strength. Fields may have been connected in parallel, when designed for series, in which case they will run hot.

(b) Applied e.m.f. too weak, due to long supply line, or too small wire in branch circuit connecting with motor. These conditions would not affect the motor running light, but when a heavy load is thrown on, the speed would fall below standard.

(c) If the motor is of the series type, it may be overloaded.

Speed of Motor Too High.—Caused by:

(a) Weak field strength, due to short circuit, wrong connections, improper winding. Part of the field winding may be connected in opposition to the other part, as for instance in a compound motor, the series coils may be connected so as to oppose the action of the shunt winding, in which case the speed of the motor will increase as the load increases, until if overloaded, the excessive armature current due to weak fields will finally cause the fuses to blow or perhaps damage the armature winding. In case the trouble is due to field strength, it cannot be remedied by the addition, or the removal of wire. The only remedy is a re-winding of the field magnets with larger wire if the field is weak, or with smaller wire in case there is too great a field strength.

(b) If the motor is of the series type it will speed up in case of light load. Therefore, a series motor requires constant regulation when carrying a variable load.

Sparking at the Brushes.—Sparking at the brushes of compound motors is generally due to improper connection of the field coils; since this type of motor is wound with series fields, either opposing or assisting the shunt fields. In the case of series or shunt motors, sparking at the brushes may be due to any one of the following causes:

(a) Surface of commutator rough; bearing surface of brushes worn, jagged or uneven; dirt on commutator.

(b) Brushes leaving the commutator at intervals, due to insufficient tension of the springs which keep the brushes in contact with commutator.

(c) Bearing surface of brushes either too narrow or too wide. If too narrow, it will break contact with one commutator bar, before coming in proper contact with the next bar. If too wide, it may short-circuit several coils, and the breaking of this current will cause sparking.

(d) Brushes may not be correctly spaced. They should be diametrically opposite each other, except in some special types of machines.

(e) Brushes may not be in the proper position. They should be at the neutral point, which is found by slightly shifting the brushes back and forth on the commutator until the point of least sparking is found. Variations in the load also require a slight change in position of brushes to prevent sparking.

Changing Direction of Rotation.—This is accomplished by reversing the connections of either the field circuit or the armature. Reversal of both will not affect the direction of motion of the armature.

CHAPTER IX

ARMATURE WINDINGS FOR ALTERNATING-CURRENT MOTORS

Stationary and Rotating Armatures.—In all direct-current motors the field is stationary and the armature is the rotating part, while in alternating-current motors, the armature may be either the rotating or the stationary part, depending upon the type of machine and its construction.

In the case of small synchronous motors, the armature is usually the rotating part; while in the case of large synchronous motors, it is usually the stationary part.

In the case of the commutator types of motors, the armature is the revolving part, as in the direct-current motors, and the windings are very similar to the windings for direct-current motors.

The winding of the stator of the induction motor is practically the same as the armature winding of a revolving-field synchronous motor. The rotor of the induction motor may be of either the squirrel cage or wound type. In the squirrel-cage construction there are a number of copper bars imbedded in slots in the surface of the armature, and these are all connected together at the ends of the armature by metal rings of low resistance. The wound rotor has a winding similar to the winding of the stator, and the terminals of this winding are brought out to an

external controlling resistance by means of slip rings and brushes.

In general, the windings for alternating-current motors are practically the same as the windings for the armature of the alternating-current generator, and only a few of the types will be discussed in the following sections. The reader will have to refer to some of the standard books on armature windings for a complete discussion of the many different types.

Comparison of Direct-Current and Alternating-Current Armature Windings.—In comparing the armature windings of direct-current machines with those for alternating-current machines, it is evident, first of all, that re-entrant or closed coil direct-current windings must of necessity be two-circuit or multiple-circuit windings, that is, they must have at least two paths in parallel through the armature between the brushes. On the other hand, the armatures of alternating-current dynamos and synchronous motors may, and generally do, from practical considerations, have one-circuit windings, that is, windings having one circuit per phase.

With the exception of the Δ (delta) connected polyphase windings, and the short-circuited windings of "squirrel-cage" induction motors, both of which are of the re-entrant or closed-circuit type, the windings of alternating-current armatures are essentially nonre-entrant or open-circuit windings.

Classification of Armature Cores.—Armatures for alternating-current motors may be classified according to the form of the core into three groups, as follows:

(a) Drum armatures.
(b) Ring armatures.
(c) Disk armatures.

The ring and disk types are less stable, from a mechanical standpoint, than is the drum type. The ring armature, other things being equal, requires more wire to be wound upon it for a given output than does the drum armature and, therefore, has a greater inductance than the latter type. Drum armatures for alternating-current machines have laminated iron cores similar in construction to the armature cores for direct-current machines. This applies to alternators of either the revolving or the stationary armature type.

Armatures for alternating-current motors may be classified according to the construction of the core into two groups, as follows:

(a) Smooth-core armatures.
(b) Toothed-core armatures.

(a) In the smooth-core armature, the conductors are arranged in flat coils, lie on the surface of the core, and, in some cases, the coils are bent down over the ends of the core and fastened by end plates or by blocks of wood or fiber. In other cases the coils are flat or "pancake" shaped and of the same length as the armature core, being laid upon the cylindrical surface of the core and securely bound with wire bands. Smooth-core armatures produce a wave of electromotive force or current that is very nearly harmonic (sinusoidal) or slightly flat-topped. The inductance of a smooth-core or surface-wound armature is much less than that of a toothed-core armature.

(b) Owing largely to their weak mechanical structure, smooth-core armatures have been superseded in modern practice by the toothed-core type in which the conductors are laid in slots, the sides and bottom

of which are insulated by mica-canvas, micanite, or other suitable insulating material. The conductors, which are also insulated, being cotton covered, are usually wound into coils on formers, each coil being taped and then impregnated with insulating compound or varnish, after which they are baked in ovens for the purpose of drying them thoroughly.

This type of armature is often referred to as an iron-clad armature, owing to the fact that when the conductors are laid in the slots between the teeth, the latter usually project slightly over the conductors, thus affording a thorough protection and securing the conductors firmly in place against the action of centrifugal force. This construction also serves to shield the conductors from the racking action of the magnetic drag, due to the magnetic field.

Types of Armature Conductors.—According to the form of conductors used, armature windings for alternating-current machines may be divided into three classes, as follows:

(a) Wire winding
(b) Strap winding
(c) Bar winding

(a) Wire winding consists of machine-wound coils, formed and insulated before being placed in the slots of the armature. This type of winding is usually employed in machines having a low current output, but working on high potentials.

(b) Strap winding is made of copper strap, forged into the required shape and carefully insulated. It is adapted for machines of lower voltage and greater current output. Both the wire and the strap windings may be placed in the slots without any mechan-

ical bending. This prevents damaging the insulation. If the slots are of the partially closed type, these windings are slipped in from the end. If the slots are what is known as the open type, the coils are secured in place by wedges of hard fiber.

(c) In placing bar windings, the bars, after being carefully insulated, are slipped into the slots from one end of the armature and the end or cross-connections are then bolted and soldered to the bars. The over-

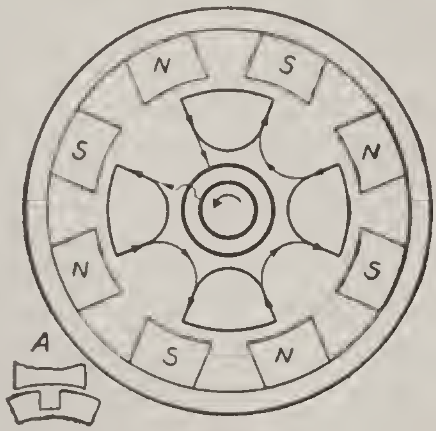


Figure 78.—Single-Phase Winding, One Slot per Pole.

hanging tips of toothed slots serve to firmly secure the bars in place, thus dispensing with band or binding wires on the armature core. Bar windings usually have one or two bars per slot.

Single-Phase Windings.—Figure 78 shows a common type of single-phase winding, known as the *concentrated type,* having one coil to each pair of poles, or one slot per pole. The sketch *A,* at the lower left-hand corner of the cut, is a sectional view of a portion of the armature core and shows one of the slots containing the conductors which form one side of a single armature coil standing opposite to the pole of a field magnet. In the diagram, the dark lines en-

closing the sector-shaped figures represent the coils, and the lines of lighter shade represent the connections between the coils.

The radial parts of the sector-shaped figures represent the portions of the coils that lie in the slots of the armature core, and the curved parts of the sectors represent the portions of the coils that lie at the ends of the core. The collecting rings are represented by two small dark circles at the center of the cut,

Figure 79.—Single-Phase Winding, Two Slots per Pole.

one being shown inside the other for the sake of clearness.

The direction of the current at a given instant of time is shown by the arrows. At a given instant, all electromotive forces under *N* poles are in one direction, and all electromotive forces under *S* poles are in the opposite direction. The explanations here given apply also to Figures 79, 80, and 82. In Figure 79 is shown a single-phase winding, known as the *distributed type*, in which there are two slots per pole, all the coils being connected in series.

A sectional view of a portion of the armature core is shown by the small sketch *A* at the lower left-hand

corner of Figure 79. It will be noted that in this case there are two slots standing opposite one pole face. The direction of the induced electromotive force at a given instant is shown by the arrows.

Two-Phase Windings.—A two-phase winding consists essentially of two independent single-phase windings on the same armature, each winding being connected to a separate pair of collecting rings, thus necessitating the use of four collecting rings. Such an arrangement is shown in Figures 80 and 82.

Figure 80.—Two-Phase Winding, One Slot per Pole per Phase.

In Figure 80 the four collecting rings are represented at the center of the diagram by two small dark circles, one within the other, and two dotted circles surrounding these, it being necessary to so place them in order to show the connections. The winding shown in Figure 80 is of the concentrated type, that is, one slot per pole for each phase, one phase being represented by the full lines, while the other phase is shown by dotted lines. For the sake of convenience the two phases will be designated by *A* and *B*, phase *A* in Figure 80 being represented by full lines and phase *B* by dotted lines.

Figure 81 shows the arrangement of the slots for a two-phase concentrated winding. The slots marked a_1, a_2, a_3, etc., contain the conductors comprising phase A, while the slots marked b_1, b_2, b_3, etc., contain the conductors comprising phase B. The slots designed to carry the A windings are also indicated by dark lines, while the B slots are dotted. Phase A winding passes along slot a_1 from the front to the back end of the armature core; then from back to front in slot a_2; then from front to back in slot a_3; then from back to front in slot a_4; and so on, the

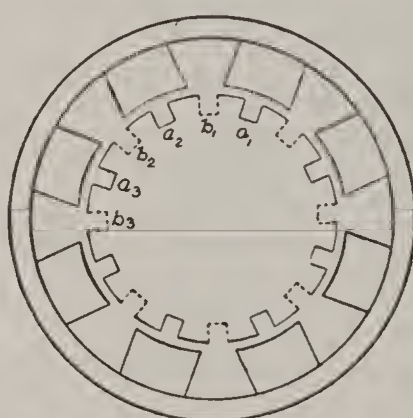


Figure 81.—Two-Phase Drum Armature Core, One Slot per Pole per Phase.

various conductors located in slots a_1, a_2, a_3, etc., being joined in series by connectors at the front and back, while the two terminals are connected to two collector rings, as shown in Figure 80.

The phase B winding, Figure 81, passes along slot b_1 from the front to the back end of the armature core; then from back to front in slot b_2; then from front to back in slot b_3; then from back to front in slot b_4; and so on until all the b slots are occupied by conductors, which are also joined in series at the back and the front by connectors similar to the A winding.

The terminals of the B winding are then connected to two collector rings, these being represented by dotted lines in Figure 80.

Figure 82 shows a two-phase distributed winding, there being two slots per pole for each phase. The

Figure 82.—Two-Phase Winding, Two Slots per Pole per Phase.

heavy dark lines represent phase A, while phase B is indicated by dotted lines. Figure 83 shows an end view of a portion of a two-phase armature with its A and B windings distributed in two slots per pole. The coils belonging to the A winding are of a lighter

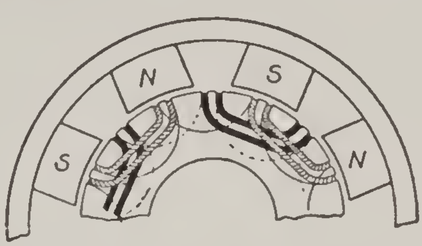


Figure 83.—End View Two-Phase Distributed Winding, Two Slots per Pole per Phase.

shade in order to distinguish them from the B winding.

The connections between the coils of the A winding are represented in both Figures 82 and 83 by full lines, while the dotted lines shown the connections

between the coils of the B winding. A brief study of Figures 80, 81, and 82 will enable the student to fully comprehend the meaning of the term *difference in phase*, and what causes it. It has already been explained that the electromotive force generated in an armature conductor reaches its maximum value when that conductor is directly under, or in front of, a pole face, and is cutting the lines of force at right angles to their direction. It has also been explained that the conductors carrying phase A are represented in Figure 80 and 82 by full lines; and the conductors carrying phase B, by dotted lines.

Comparing Figures 80 and 82 with Figure 81, it will be noted that the full line, or A-phase, conductors are carried in slots a_1, a_2, a_3, a_4, etc.; and in the position shown, these slots are directly in front of the pole faces. Therefore, the value of the electromotive force induced in the A-phase conductors is, at this particular instant of time, at a maximum; while at the same instant the B-phase conductors, represented by the dotted lines and carried in slots b_1, b_2, b_3, b_4, etc., are, as shown in Figure 81, midway between adjacent poles and moving in a direction parallel with, instead of at right angles to, the lines of force. Consequently, the value of the electromotive force induced in the B conductors is for the moment at zero. During the time that a given conductor, or a given bunch of conductors, moves from the center of a given north pole to the center of the next north pole, the electromotive force in the conductor, or bunch of conductors, passes through a complete cycle of values, that is, from maximum to zero and from zero to maximum.

In the two-phase alternator, the electromotive

forces in the respective windings, as for instance, winding A and winding B in Figures 80 and 82, arrive at their maximum values 90 degrees, or one-fourth of a period, apart.

Three-Phase Windings.—A three-phase winding consists of three independent single-phase windings arranged on the same armature core and having their terminals connected to three collecting rings, as shown in Figures 86 and 87. This system of winding may perhaps be better understood if we consider for a moment three similar single-phase armatures, mounted side by side on the same shaft. These three armatures may be designated by A, B, and C. They are exact counterparts of each other in every detail, each having as many slots as there are field poles, and all three armatures are to be revolved in the same magnetic field. Let time be reckoned from the instant that a given slot of armature A is directly under, or in front of, an N-pole face. The time consumed by this armature slot in passing from the center of one N-pole face to the center of the next N-pole face may be expressed by t. Then the armature B is to be so mounted on the shaft that its slots will be squarely under, or in front of, the pole faces at the instant $\frac{1}{3}t$; while the armature C is to be so mounted on the shaft that its slots are directly under, or in front of, the pole faces at the instant $\frac{2}{3}t$. The time t represents a complete cycle, and the three electromotive forces generated by the three armatures arranged as described will consequently be 120 degrees apart in phase. A three-phase alternator is simply a combination of three single-phase alternators, with this exception, that instead of there being three separate armatures, the windings are placed

upon a single core having three slots per pole. Figure 84 shows the arrangement of the slots for such a winding.

The slots designed to carry the phase A winding are represented by dark lines marked a_1, a_2, a_3, a_4, etc. Those designed to carry phase B windings are shown by dotted lines marked b_1, b_2, b_3, etc., while the slots belonging to phase C winding are drawn in lightly shaded lines and marked c_1, c_2, c_3, etc. The arrangement of the windings is as follows: The A

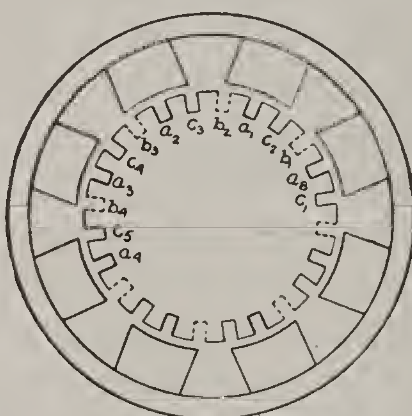


Figure 84.—Three-Phase Drum Armature Core, One Slot per Pole per Phase.

winding passes from the front to the back end of the core by way of slot a_1; then from back to front by way of slot a_2; then from front to back in slot a_3; then from back to front by way of slot a_4; returning to the back by way of slot a_5, and so on until the terminal is finally brought to the front end of the armature by way of slot a_8. The B winding passes from front to back in slot b_1; returns to the front in slot b_2; again passes to the back in slot b_3; returning to the front in slot b_4; and so on until its terminal emerges from slot b_8. The C winding enters slot c_1 through which it passes to the back end of the arma-

ture; returning to the front in slot c_2; then from front to back by way of c_3; returning by way of c_4; and so in in regular order until its terminal finally appears at the front by way of slot c_8. There being one slot per pole for each winding (*A*, *B*, and *C*). the winding just described is of the concentrated type.

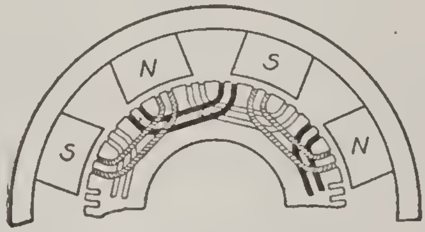


Figure 85.—End View Three-Phase Distributed Winding. Two Slots per Pole per Phase.

Figure 86.—Three-Phase Concentrated Winding, Y Connected.

Distributed windings are also frequently used for three-phase alternators. This style of winding is shown in Figure 85, which shows a portion of a three-phase armature with its *A*, *B*, and *C* windings each distributed in two slots per pole, the coils belonging to the respective windings being differently shaded in order to distinguish them. Figures 86 and 87 show the winding and connections of a three-phase arma-

ture, the winding being of the concentrated type. There being three circuits in a three-phase alternator, it follows that if they are to be entirely independent, six collector rings must be used, two for each wind-

Figure 87.—Three-Phase Concentrated Winding, △ Connected.

ing; however, the circuits may be kept practically independent by using four collector rings and four mains, one collector ring being common to all three phases.

CHAPTER X

COMMERCIAL TYPE OF ALTERNATING-CURRENT MOTORS

General Classifications.—Alternating-current motors may be divided into three classes, with reference to the fundamental principles of operation, as follows:

(a) Synchronous motors
(b) Induction motors
(c) Commutator motors

In some cases a motor may be a combination of two of the above types, as, for example, a single-phase induction motor may be so constructed that it will start as a repulsion motor when a good starting torque is required.

Alternating-current motors may be divided into four classes, with reference to their speed characteristics, as follows:

(a) Constant-speed motors
(b) Multi-speed motors
(c) Variable-speed motors
(d) Adjustable-speed motors

(a) The constant-speed alternating-current motor is one whose speed does not change at all or a very small amount unless there is a change in the frequency of the current being supplied to it. The synchronous motor is a good example of this type.

(b) The multi-speed alternating-current motor is one that can be operated at several speeds, each speed being practically constant for all loads within the capacity of the machine. The induction motor having a stator wound so that the number of poles can be changed while the motor is in service is a good example of this type.

(c) The variable-speed alternating-current motor is one whose speed varies with the load. The series alternating-current motor is a good example of this type.

(d) The adjustable-speed alternating-current motor is one whose speed is practically constant when once adjusted, regardless of the load, so long as the load does not exceed the capacity of the machine.

SYNCHRONOUS MOTORS

Fundamental Principle of the Synchronous Motor.—Considered from an electrical and mechanical standpoint, the synchronous motor is identically the same as the alternating-current generator; in fact, the same machine is often used as either a generator or a motor, according to circumstances and the demands of service. The compounding of an alternator, if the machine has one, is disconnected when the machine is operated as a motor.

Consider for a moment an alternating-current generator that is being driven by power supplied by a small steam engine or an auxiliary motor. When a given armature conductor of this generator is directly under, or in front of, a north magnetic pole of the field, the current in the conductor is in such a direction that the force which the field exerts on the conductor tends to oppose the motion of the

armature. When the same conductor has moved sufficiently to be under a south magnetic pole of the field, the direction of the current will be reversed, and the force produced by the magnetic field will still oppose the motion of the armature. The power required to drive the armature against these opposing forces is the mechanical power of the engine or motor driving the generator, which is transformed into electrical power and supplied to the circuits connected to the terminals of the machine. The field magnets of the alternator are excited by means of direct current from a machine called an *exciter*, and their polarity remains constant so long as there is no reversal of the direct current in their windings.

Now, suppose an alternating current be caused to flow through the armature winding of the alternator by connecting it to some outside source such as a second alternator. If the speed of the armature is such that a given armature conductor moves from the middle of a north pole to the middle of a south pole during the time of one alternation or one-half cycle of the supplied current; and if the direction of the current in the armature conductor is such that when the given conductor is under a north magnetic pole of the field the force exerted by the magnetic field upon the conductor helps, instead of opposing the motion of the armature; then the driving engine or auxiliary motor may be dispensed with, and the armature of the alternator will continue to revolve at constant speed, provided the frequency of the supplied alternating current is constant. The revolving armature may now be used to deliver mechanical power to other machinery; and the machine, which was originally an alternator, will now be operating

as a synchronous motor. Synchronous motors may be designed to operate on either single-phase or polyphase systems, and are called *synchronous* because they always run in synchronism with, that is, at the same frequency as, the alternator supplying current to them. Direct current is always required for the field excitation of the synchronous motor, whether single-phase or polyphase. This exciting current is sometimes supplied by a direct-current generator which may be mounted on the shaft of the motor or driven by means of a belt, but in the majority of cases the current is taken from an entirely separate source.

Speed of Synchronous Motors.—The speed of the synchronous motor cannot change unless the speed of the generator that supplies it with current changes; but this does not imply that the motor always runs at the same speed (r.p.m.) as the generator. The speed of the motor and the generator will be the same if the motor happens to have the same number of poles as the generator.

Representing the speed of the motor in revolutions per minute by S, the frequency of the current supplied to the motor by f, and the number of magnetic poles the motor has by p, then the value of the speed may be determined by the following equation:

$$S = \frac{2 \times f \times 60}{p}$$

Examples.—1. Determine the speed of an 8-pole synchronous motor when it is supplied with current from a 60-cycle alternator.

Solution.—Substituting directly in the above equation gives

$$S = \frac{2 \times 60 \times 60}{8} = 900 \text{ r.p.m.}$$

2. How many poles should a synchronous motor have in order to operate at a speed of 600 revolutions per minute when it is supplied with current from a 60-cycle alternator?

Solution.—Substituting directly in the equation for speed gives

$$600 = \frac{2 \times 60 \times 60}{p}$$

and then solving this equation for p gives

$$600\,p = 7200$$
$$p = 12$$

Adjustment of the Current in the Armature Winding of a Synchronous Motor.—The current in the armature circuit of a direct-current motor is equal to the difference in the values of the impressed voltage and the counter-electromotive force divided by the resistance of the armature circuit. Any change in the value of this current, with a constant impressed voltage and constant armature resistance, is produced by a change in the counter-electromotive force, due to a change in either the field strength or the speed, or perhaps both. The speed of a direct-current motor is always such that the sum of the counter-electromotive force and the resistance drop is equal to the impressed voltage.

There is a counter-electromotive force induced in the armature winding of a synchronous motor, and its value, as in the case of the direct-current motor, depends upon the speed of the motor and the magnetic flux per pole. Since the speed of the synchronous motor is constant, the only means by which the value of the counter-electromotive force may be changed is to change the magnetic flux per pole by changing the exciting current. If all the required

changes in the values of the current in the armature winding, due to a change in load, had to be taken care of by changing the magnetic flux per pole, the operation of the motor would be very unsatisfactory. This change in magnetic flux per pole, however, is not required, for the required change in the value of the current in the armature circuit of a synchronous motor—due to a change in load—is produced by a change in the phase relation of the impressed voltage and the counter-electromotive force. If the load on the motor, with a constant field excitation, be increased, the position of the armature—when the current is a maximum or passing through zero value—lags with respect to the poles of the magnetic field and, as a result, the phase relation of the counter-electromotive force and the impressed voltage will change and more current will flow in the armature and thus produce the necessary torque to drive the increased load, unless the load exceeds the capacity of the machine. The current supplied to the armature winding may be in phase with the impressed voltage or it may lead or lag the impressed voltage, depending upon the value of the excitation.

With an increase in load on the motor, the armature lags more and more with respect to the poles of the magnetic field. This increase in lag of the armature allows more current to flow through the armature winding; but as the current increases in value, its phase relation with respect to the impressed voltage is changing, namely, the angle between the armature current and the impressed voltage increases with an increase in the value of the current and, as a result of the increase in this angle, there will be a decrease in the power factor of the circuit supplying

current to the motor. The power supplied to the motor will continue to increase with an increase in the lag of the armature as long as the product of the power factor and the armature current continues to increase; but a point is finally reached where the power factor decreases faster than the current increases, and beyond this point the motor will not develop ample torque to carry its load. When this point is reached, the motor will "break down" and stop, for the very simple reason that it is not developing enough torque to handle its load.

Hunting of the Synchronous Motor.—When the load on a synchronous motor is suddenly increased, the result is a momentary change in the speed of the revolving part of the machine, thus causing a change in the phase relation of the counter-electromotive force in the armature winding and the impressed voltage. This change in phase relation between the counter-electromotive force and the impressed voltage results in an increase in current in the armature winding. If the speed of the revolving part changes very rapidly, there is liable to be a current produced in the armature winding in excess of that required to drive the load, which results in the revolving part of the machine speeding up and causing a decrease in current. The total increase in speed may be such as to cause the current to be lowered below the value required to carry the load, and the speed then starts to decrease, then again increase. This action of the synchronous motor is called *hunting*.

The hunting action of a synchronous motor is frequently a source of great annoyance, being generally accompanied with great variations in the value

of the current and also a rapid rise and fall of the voltage between the terminals of the motor. Hunting is frequently caused by periodic changes in the speed of the prime mover operating the generator supplying current to the motor, especially in cases where gas engines are used. The tendency of the motor to hunt is greatest where several synchronous motors are operated in parallel on the same mains. When a number of synchronous motors are in parallel on the same circuit, very large currents may circulate between the motors and thus cause serious disturbances, but this condition can be improved by connecting a few induction motors to the circuit, thus forming what may be termed a mixed circuit.

Hunting may be reduced by the use of heavy copper frames or dampers arranged so as to surround the pole pieces. This arrangement may be made more effective by cutting slots in the faces of the pole pieces and placing copper conductors therein. The currents induced in these damping devices tend to prevent sudden changes in the magnetic field and thus increase the tendency toward synchronism.

Field Excitation and Power Factor.—The current supplied to non-synchronous motors, such as the induction motor, is always lagging the impressed voltage; while the current supplied to the synchronous motor may be made to lead or lag the impressed voltage at will. This control of the phase relation of the current with respect to the impressed voltage is accomplished by varying the strength of the magnetic field. The counter-electromotive force induced in the armature winding of a synchronous motor may be changed by changing the field strength, namely, an increase in field strength means an increr ·in

counter-electromotive force, and a decrease in field strength means a decrease in the counter-electromotive force. Since the speed of the synchronous motor is constant, the counter-electromotive force will vary directly as the field strength.

A clear understanding of the effect of a variation in field current upon the value of the power factor of an induction motor may be obtained by the use of several simple diagrams, as shown in Figures 88, 89 and 90. The diagram in Figure 88 represents a condition when the motor is taking a lagging current. The line OE represents the impressed voltage,

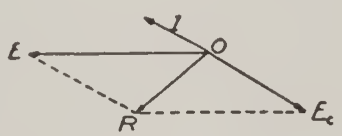


Figure 88.—Diagram of Synchronous Motor Taking a Lagging Current.

the line OE_c the counter-electromotive force, and the line OR the resultant pressure acting in the circuit. This resultant pressure produces the current in the armature of the motor, which unusually has a relatively high reactance and low resistance and, as a result, the current lags the resultant pressure between 80 and 90 degrees, but in no case can it be as much as 90 degrees. The value of pressures and the angles have been so chosen in the diagram in Figure 88 that the current I taken by the motor lags the impressed voltage by approximately 30 degrees.

The diagram in Figure 89 represents a condition of affairs when the power input to the motor is the same as in the diagram in Figure 88, but the power

factor in this case is unity and in the diagram in Figure 88 it is equal to the cosine of 30 degrees. The power component of the current in the diagram in Figure 89 is the same as in Figure 88, and the current makes the same angle with the resultant voltage *OR* as in the diagram in Figure 88. It is evident that the field excitation of the machine for

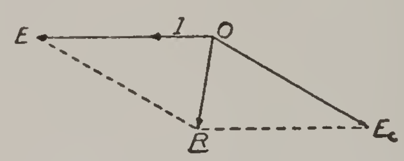


Figure 89.—Diagram of Synchronous Motor Taking a Current in Phase with the Pressure.

conditions shown in Figure 89 must be greater than for conditions shown in Figure 88, in order to increase the value of the counter-electromotive force to the required value.

The diagram in Figure 90 represents a condition of affairs when the power input to the motor is the same as in the diagrams in Figures 88 and 89; the

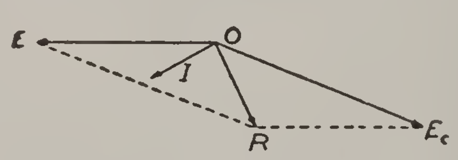


Figure 90.—Diagram of Synchronous Motor Taking a Leading Current.

power factor is equal to the cosine of 30 degrees, the same as in the diagram in Figure 88, but the current in this case is leading the impressed voltage by the same amount it is lagging the impressed voltage in the diagram in Figure 88. The counter-electromotive force in the diagram in Figure 90 is greater than it is in either of the other two diagrams, in order that the motor take the same power.

The field excitation of the motor which gives unity power factor for some particular load is called the *normal excitation* of the motor for that load. If the excitation be decreased below this value, the current supplied to the motor will lag the impressed voltage; and if the excitation be increased above this value, the current will lead the impressed voltage, as indicated in the diagrams in Figures 88, 89, and 90.

Synchronous Phase-Modifier.—As shown in the previous section, the synchronous motor, when overex-

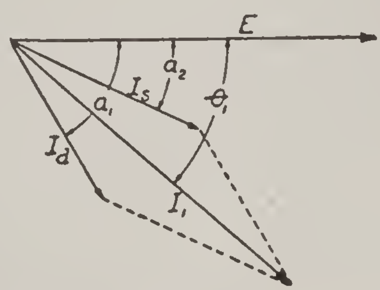


Figure 91.—Combining Two Lagging Currents.

cited, takes a leading current from the circuit to which it is connected. If there are other electrical devices connected to the same circuit that the synchronous motor is connected to, and they are taking a lagging current from the circuit, then the leading current to the synchronous motor and the lagging current will combine to form a resultant current which will be displaced from the line voltage by a smaller angle than if both the currents were leading or lagging. This resultant relation can be shown by reference to Figures 91 and 92. The diagram in Figure 91 represents a condition when the current I_d, taken by an induction motor, lags the impressed voltage E by the angle a_1; and the current I_s, taken by the synchronous motor, also lags the impressed

voltage by the angle a_2. The resultant current I_1 is a combination of I_d and I_s and it makes an angle θ_1 with the impressed voltage E. The power supplied to such a combination is given by the following equation:

$$P_1 = E \times I_1 \times \cos \theta_1$$

The diagram in Figure 92 corresponds to a condition when the field current of the synchronous motor has been adjusted so that its armature current leads the impressed voltage and the value of the

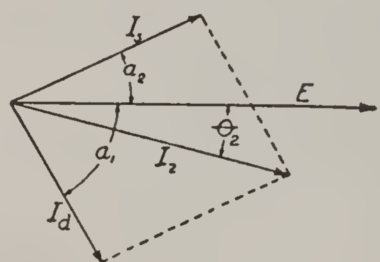


Figure 92.—Combining a Leading and Lagging Current.

current supplied to the induction motor and its phase relation with respect to the impressed voltage remain the same as in the diagram in Figure 91. The resultant current I_2 in this second case makes an angle θ_2 with the impressed voltage, and the total power supplied to the combination is given by the following equation:

$$P_2 = E \times I_2 \times \cos \theta_2$$

If the total power supplied to the combination is the same in both cases, that is,

$$P_1 = P_2$$

then

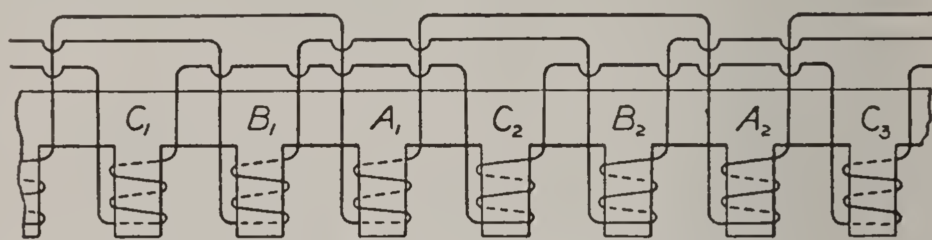
$$E \times I_1 \times \cos \theta_1 = E \times I_2 \times \cos \theta_2$$

It is apparent from the diagrams that θ_2 is less than θ_1 and, hence, the $\cos\theta_2$ will be greater than $\cos\theta_1$, and the value of I_2 will be less than the value of I_1. The synchronous motor, when used as indicated in the diagram in Figure 92, reduces the losses in the main circuit by reducing the value of the current the line must carry in order to transmit a certain power, and also improves the power factor of the main circuit, but not of either motor circuit alone. When used for the purpose of improving the power factor of a circuit, the synchronous motor is called a *synchronous phase-modifier*, and it may or may not be delivering mechanical power when used in this way.

INDUCTION MOTOR

Rotating Magnetic Field.—Suppose the projecting arms or poles on the field frame of a dynamo be divided into three groups and the poles belonging to one group marked A_1, A_2, etc., those of another group B_1, B_2, etc., and those of the third group C_1, C_2, etc., as indicated in Figure 93, which shows the field structure laid out flat. If a winding be placed on the poles belonging to the different groups, alternate coils being wound around the cores in opposite directions and each of these windings connected to a source of direct-current, the lower ends of the poles belonging to any one group will be magnetized alternately north and south. If an alternating current be sent through the windings, the polarity of each pole will reverse twice during each cycle of the current and their strength will be changing in value as the value of the current changes. By connecting the three windings to the different phases of a three-phase

circuit, any three poles that occur in succession around the frame will not be magnetized to a maximum polarity at the same time. The time required for the maximum polarity to advance from one pole



I	N	N	N	S	S	S	N
II	S	N	N	N	S	S	S
III	S	S	N	N	N	S	S
IV	S	S	S	N	N	N	S
V	N	S	S	S	N	N	N
VI	N	N	S	S	S	N	N

Figure 93.—Producing a Rotating Magnetic Field.

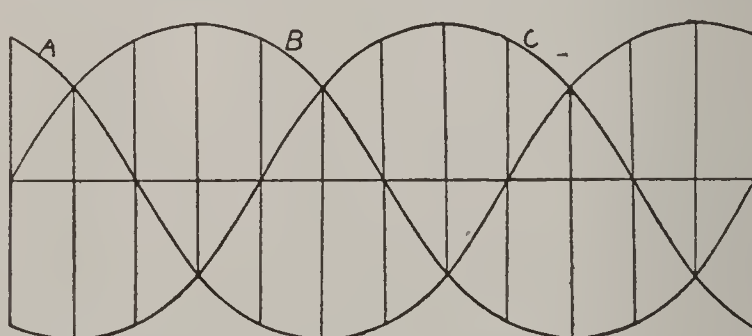


Figure 94.—Three Currents Displaced in Phase by 120 Degrees.

to the next is one-third of a half period or one-sixth of a period. The maximum polarity passes from one pole to another around the magnetic frame, which results in what is called a *rotating magnetic field.*

Assume that three curves A, B, and C, Figure 94, represent the currents in the three different circuits about the A, B, and C groups of poles. Starting with

the current in the B winding at a maximum positive value and in such a direction through the winding that the lower end of the pole marked B_1 is a north pole, then the current in the phases A and C are negative with respect to the current in the phase B at this time, but the windings A and C are so connected that the lower end of the poles marked A_1 and C_1 are both north poles but of less strength than the pole B_1. At the same time the lower end of poles A_2, B_2, and C_2 will all be south magnetic poles. The currents in the different windings do not remain constant and, as a result, the strength of the poles marked B decrease in value, those marked A increase in value, and those marked C decrease in value until the current in the C winding reaches zero value, when the poles marked C start to increase in value but of opposite polarity, etc. At the end of one-sixth of a cycle, pole A_1 is of maximum north polarity and poles B_1 and C_2 are of the same polarity as A_1, but of less strength. At this time poles A_2, B_2, and C_1 are all south poles, as indicated in line II. At the end of the next one-sixth of a cycle, the polarity of the poles will be as indicated in line III. From an inspection of this figure, it is readily seen that the magnetic field is moving toward the right.

In the production of the rotating field for commercial purposes, the windings connected to the various phases are usually distributed and overlap each other instead of being confined to certain definite localities, as indicated in the upper part of Figure 93.

Speed of the Rotating Magnetic Feld.—The speed at which a magnetic field rotates when it is produced, as explained in the previous section, may be determined as follows: Let f represent the frequency

of the supplied current and p the number of magnetic poles per phase, and since two magnetic poles correspond to one cycle, the time required for one revolution of the magnetic field will be equal to

$$\text{time per revolution} = p \div 2 \times f$$

and

$$\text{number of revolutions per second} = 2 \times f \div p$$

Example.—If there are 10 magnetic poles in the field structure of an induction motor, at what speed will the magnetic field rotate when the winding is supplied with 25-cycle current?

Solution.—Substituting in the above equation for speed in r.p.s. gives

$$\text{r.p.s.} = 50 \div 10 = 5$$

and the revolutions per minute (r.p.m.) will be

$$\text{r.p.m.} = \text{r.p.s.} \times 60$$

or

$$5 \times 60 = 300$$

Fundamental Principle of the Induction Motor.—If a hollow metal cylinder be mounted on an axis inside of a rotating magnetic field, there will be an electromotive force induced in the cylinder, due to the relative motion of the magnetic field and the cylinder, and this electromotive force will produce a current in the cylinder which will react upon the magnetic field and thus produce a force tending to cause the cylinder to rotate. The path taken by the current in the cylinder, due to the induced electromotive force, is not very well defined and, as a result, it will not be very useful in producing a force tending to turn the cylinder. This difficulty is overcome by sloting the cylinder in a direction parallel to the axis about which it rotates.

The magnetic flux between the poles of the rotating magnetic field can be greatly increased, with the

same current in the winding, by providing an iron core to carry the conductors in which the induced current is to flow.

Construction of the Induction Motor.—There are two essential parts in every induction motor and these are:

(a) The stator
(b) The rotor

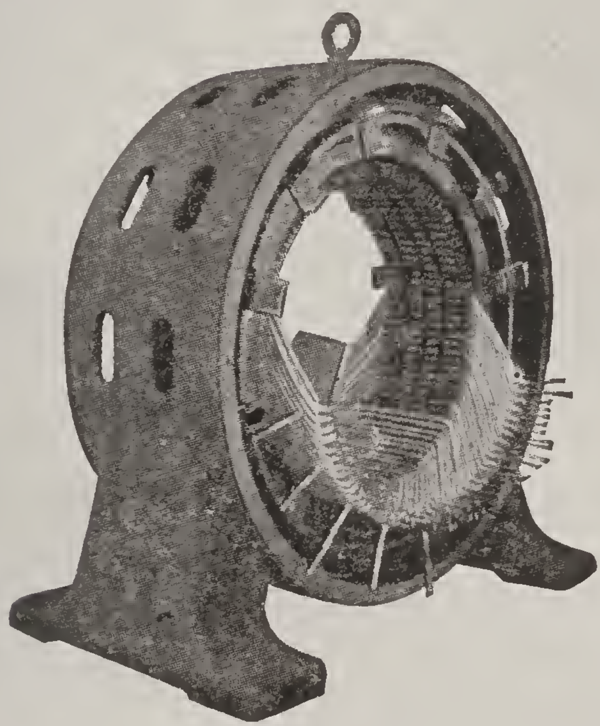


Figure 95.—Stator of Induction Motor, Partly Wound.

(a) The stator of an induction motor is the stationary part, and its construction is practically the same as that of the armature of a rotating-field alternator. The stator windings are usually placed in slots cut in what is called the *stator core*, which is a laminated structure supported by a cast-iron frame, instead of being wound on poles as shown in Figure 93. The stator core of a small induction motor is shown in Figure 95.

(b) The revolving part of the induction motor is called the *rotor,* and induction motors are divided into two classes depending upon the construction of the rotor.

(1) Squirrel-cage type
(2) Slip-ring type

(1) The squirrel-cage rotor consists of metal bars or rods imbedded in slots cut on the surface of a cylindrical laminated iron core. The ends of these

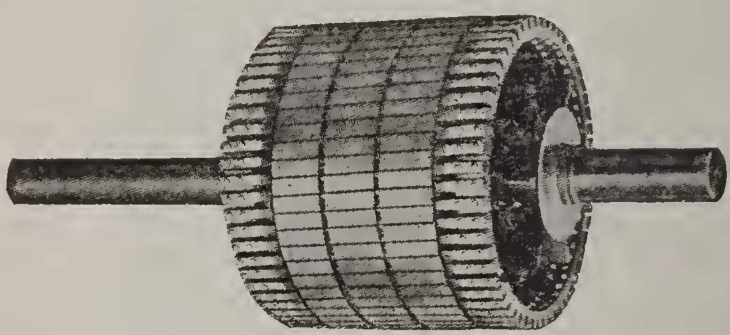


Figure 96.—Squirrel-Cage Rotor.

metal bars are connected to copper rings placed at each end of the core. The resistance of such a winding is usually very low because the bars are all connected in parallel. A squirrel-cage rotor is shown in Figure 96.

(2) A slip-ring, or wound, rotor is one provided with a winding similar to those on the stator, and the terminals of this winding are connected to slip rings mounted on the shaft. The rotor winding is connected to the external circuit by means of these slip rings, which provides a means of starting and controlling the motor by being able to vary the resistance of the rotor circuit.

The rheostat, by means of which the resistance of

the rotor circuit is varied, is sometimes placed in the rotor structure of small motors, which does away with the necessity of the slip rings, the resistance being cut in or out of circuit by means of a rod which projects through the hollow shaft.

Operation of the Induction Motor.—In the operation of the induction motor there is both a generator and a motor action.

(a) Generator Action.—The flux of the rotating magnetic field produced by the current in the stator windings cuts across the conductors on the surface of the rotor and induces in them an electromotive force, which causes a current to flow in the rotor circuit.

(b) Motor Action.—The current produced in the conductors on the rotor and the rotating magnetic field react upon each other and produce a torque, the direction of which is the same as the direction in which the magnetic field revolves.

Speed of the Induction Motor.—Assuming the rotor of an induction motor were to revolve at the same speed as the rotating magnetic field produced by the current in its stator, there would be no relative movement of the conductors on the rotor and the magnetic field, hence, there would be no induced electromotive force in the conductors on the rotor and, as a result, there would be no current in the rotor winding. It is apparent that the rotor could never run at the same speed as the rotating field, unless it was driven from some outside source of power, as there would be no torque produced on account of there being no current in the rotor windings. In order that there be a current in the rotor winding there must be an induced electromotive force

and, hence, the speed of the rotor must be less (in the case of a motor) than that of the magnetic field. With a decrease in speed of the rotor, there is an increase in rotor current and, hence, an increase in torque. The speed of the motor will become constant when the developed torque is just sufficient to drive the load, unless the load exceeds the capacity of the motor. As the load changes, there will be a change in the torque the motor must develop and, hence, there must be a change in rotor current which is produced by a change in speed of the rotor, resulting in a change in the value of the induced electromotive force in the rotor. If the load increases, the speed will decrease; and if the load decreases, the speed will increase.

Slip of the Rotor.—The difference in the speed of the rotating magnetic field and that of the rotor is called the *slip* of the rotor. The slip is approximately proportional to the load for all loads within the range of the normal capacity of the motor. Representing the speed of the magnetic field by S, and the speed of the rotor by S^1, then the slip of the rotor in per cent. may be computed by means of the following equation:

$$\text{per cent slip} = \frac{S - S^1}{S} \times 100$$

The slip of the rotor of an induction motor may be easily measured, unless it becomes excessive, by what is called the *stroboscopic method.* Mark as many equally-spaced radial lines on the end of the shaft as there are poles on the motor and illuminate these lines by means of an arc lamp connected to the circuit supplying current to the stator of the

motor. When the motor is in operation, the radial lines appear to rotate in a direction opposite to the direction in which the rotor is rotating, and the speed of this apparent rotation is proportional to the slip of the rotor.

The light from the arc lamp pulsates in value, and if the rotor was revolving at synchronous speed, the radial lines would advance the angular distance of one pole pitch for each pulsation of the light, and the lines would appear to stand still. The speed of the rotor is less than the speed of the magnetic field and, as a result, the angular advance of the lines is less than the angular distance of one pole pitch, and successive pulsation of the light shows the lines in a position slightly behind that which they occupied at the previous pulsation. The per cent slip may be determined as follows: Let f represent the frequency of the current supplied to the motor and t the rate at which the radial lines drop back per minute, then

$$\text{per cent slip} = \frac{t}{f \times 60 \times 2} \times 100$$

Example.—A 4-pole induction motor is operated on a 60-cycle circuit. In determining the slip by the stroboscopic method, the radial lines in the end of the shaft dropped back at the rate of 108 in one minute. What was the slip in per cent?

Solution.—Substituting in the above equation gives

$$\text{per cent slip} = \frac{108}{60 \times 60 \times 2} \times 100 = 1.5$$

Torque of the Induction Motor.—From the discussion of the induction motor in the previous sections, it might be supposed that the maximum torque would be produced at zero speed, since the induced electro-

motive force in the rotor, and hence the rotor current, is then a maximum. The frequency of the induced current in the rotor is directly proportional to the slip of the rotor, and the rotor current lags behind the induced electromotive force more and more as the slip increases, due to the increase in reactance of the rotor circuit. The lagging current tends to set up a flux which is opposed to that produced by the current in the stator windings, and, when the slip becomes large, this demagnetizing ac-

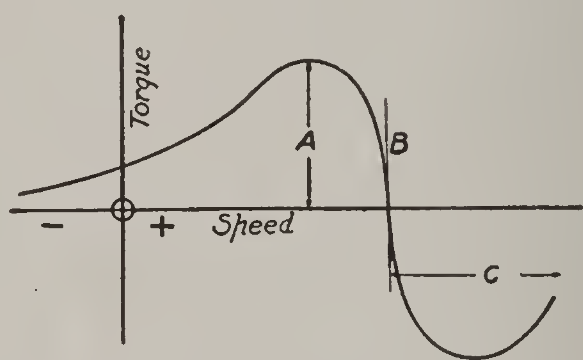


Figure 97.—Speed-Torque Curve of Induction Motor.

tion is excessive, and the magnetic flux decreases more rapidly than the rotor current increases. As a result of the demagnetizing effect of the rotor current, the speed-torque curve of an induction motor is not a straight line but has the general shape, when the resistance of the rotor remains constant, shown in Figure 97. The ordinate A represents the maximum torque, and the ordinate B corresponds to synchronous speed or zero torque.

The torque for lower speeds may be increased by increasing the resistance of the rotor circuit, which results in a smaller phase displacement of the rotor current and the induced electromotive force pro-

ducing it; hence, a smaller demagnetizing action and a greater torque.

Induction Generator.—An induction motor when operating without load takes a very small current from the circuit to which it is connected, and the speed of its rotor is very near that of the magnetic field. If the rotor be connected to some source of power and its speed adjusted to correspond to that of the magnetic field, the electrical power input to the stator will be very small, it being equal to the iron loss in the stator. By increasing the speed of the rotor or rotating it above synchronism, the stator will deliver power to the circuit to which it is connected, provided an alternating-current generator is connected to this circuit to fix the frequency. When an induction motor is used in this manner, it is called an *induction generator.* Generators of this type are very uncommon.

Induction Motor as a Frequency Changer.—An induction motor provided with a rotor having a winding with terminals connected to collector rings may be used as a frequency changer, that is, it may be used to change the frequency. When the rotor of an induction motor is held stationary, the magnetic flux produced by the current in the stator induces electromotive forces in the windings on the rotor that are of the same frequency as the electromotive forces applied to the stator. If the rotor is run at one-half speed in the direction the magnetic field rotates, the frequency of the induced electromotive forces in the rotor windings will be one-half the frequency of the electromotive forces applied to the stator. By driving the rotor in the opposite direction to the direction in which the magnetic field rotates, the frequency of

the electromotive forces in the rotor windings is greater than the frequency of the electromotive forces applied to the stator. Thus, if the rotor be revolved at one and one-third synchronous speed, the rotor electromotive forces will have a frequency one and one-third times as great as the stator electromotive forces.

The speed of the rotor, when the induction motor is used as a generator, is determined by the speed of the prime mover.

COMMUTATOR MOTORS

Action of the Direct-Current Shunt Motor When Supplied with Alternating Current.—If a direct-current shunt motor be connected to an alternating-current circuit, the current in the armature and field circuits will not be in phase, due to the difference in the relation of the resistance and the reactance for the two circuits. The armature circuit has a much lower reactance in proportion to its resistance than the field circuit and, as a result, the field and armature currents will be displaced from the impressed voltage. The magnetic flux per pole lags the field current and, hence, the angle between the armature current and the field flux is greater than the angle between the armature and field currents.

Since the armature current and field flux are not in phase, and since their signs do not change at the same time, the torque acting on the armature—which is proportional to the product of the armature and the field flux—will not be constant in direction during the entire cycle. The net torque producing, or tending to produce, rotation is the algebraic sum of the average torques acting in opposite directions dur-

ing one complete cycle. When the armature current and the field flux are displaced in phase by 90 degrees, the sum of the torques for one cycle is zero and there is no resultant tendency for the armature to rotate.

The torque of the shunt motor can be improved by connecting the armature to one phase and the field winding to another phase of a two-phase system. This method is not satisfactory for commercial purposes, due to complications involved in its operation, low power factor of the field circuit, and principally because more satisfactory equipment is on the market.

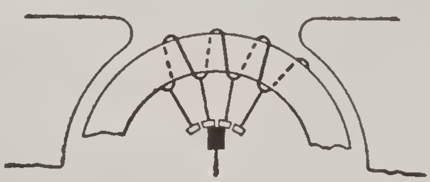


Figure 98.—Short-Circuited Coil.

Commutation is a great deal more complicated when the continuous-current motor is used on an alternating-current circuit. This can be shown by reference to Figure 98, which shows one of the coils on the armature short-circuited. When the current in the field winding changes in value, there is a change in the magnetic flux through the short-circuited coil and it acts as the short-circuited secondary of a transformer and may carry a current many times the normal current in the coil. This large current causes excessive heating of the armature and very destructive sparking when the commutator segments move from contact with the brushes.

Action of the Direct-Current Series Motor When Supplied with Alternating Current.—If a direct-cur-

rent series motor be connected to an alternating-current circuit, the current in the armature and field windings will be in phase, since they are in series; but the magnetic flux produced by the field current and the armature current will not be in phase with each other on account of the inductance of the field winding. The inductance of the field winding of the series motor, however, is much less than the inductance of the field winding of the shunt motor and, as a result, the field flux and armature current are not displaced in phase nearly so much as in the case of the shunt motor, but the commutating difficulties are practically the same.

Methods of Improving the Commutation of the Series Alternating-Current Motor.—Some of the more important methods employed in improving the commutation of a series alternating-current motor are as follows:

(a) Reducing the number of turns in each armature coil.
(b) Reducing the frequency of the circuit to which the motor is connected.
(c) Reducing the flux density in the magnetic circuit.
(d) Special devices.

(a) By reducing the number of turns in each armature coil, the electromotive force produced in the coil is reduced and, hence, the difficulties encountered during commutation are reduced. If the impedance of the short-circuited coils is reduced in the same ratio as the number of turns, there would be no improvement in commutation; but such is not the case, as the resistance is not reduced directly as the turns on account of the resistance of the connecting leads, brushes themselves, brush contacts, and commutator bars. There will be a larger number

of segments in the commutator of an alternating-current series motor than in the commutator of a direct-current series motor.

(b) The electromotive force induced in a short-circuited coil depends upon the frequency, and low frequences tend to reduce commutation difficulties.

(c) The electromotive force induced in the short-circuited coil, for a given frequency, varies with the flux through the coil or the flux density, and commu-

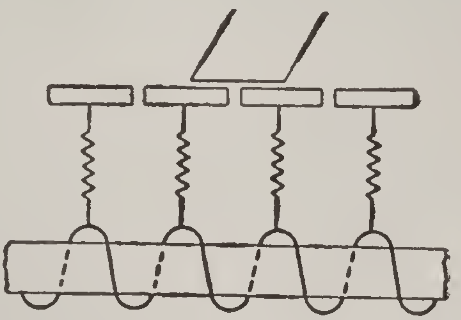


Figure 99.—Resistance Leads.

tation difficulties are less with low densities than with high.

(d) The above features in the design and operation of a series alternating-current motor improve commutation, but certain special devices have been found necessary in order to make commutation a practical success. Two of these methods are

(1) Resistance leads
(2) Balanced choke coils

(1) By connecting resistances as indicated in Figure 99, the local current in a short-circuited portion of the armature winding is reduced, since it must flow through a part of the armature winding and two of the resistances. These resistances are also in series with the external circuit and, apparently, de-

crease the efficiency of the machine by increasing the resistance losses, but it has been proven experimentally that there is an increase in efficiency as the loss due to the load current passing through the added resistances is less than the decrease in loss due to the smaller current flowing through the short-circuited parts.

(2) The connections of the choke coils are shown diagrammatically in Figure 100. The windings of these coils are so connected that their inductance is

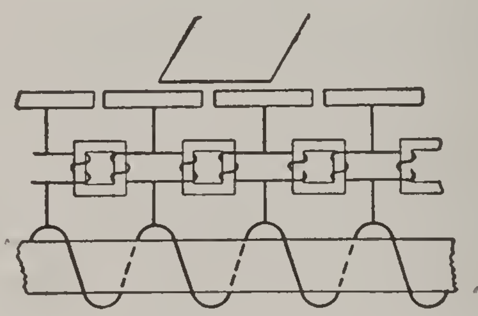


Figure 100.—Balanced Choke Coils.

cumulative in the short-circuited path, but differential to the external circuit. This combination is not altogether satisfactory as there is a balance for the external current only when the current is equally divided between the two windings.

Compensating Windings.—The armature reaction in an alternating-current motor and also the inductance of the armature winding may be greatly reduced by means of what is called a *compensating winding*. This compensating winding is a distributed winding imbedded in slots cut in the pole faces and supplied with current by either of the following methods.

(a) Current supplied inductively.
(b) Current supplied conductively.

(a) When the compensating winding is short-circuited upon itself, there will be a current induced in it from the armature by transformer action, and the magnetic fields of the two windings tend to neutralize each other. A diagrammatic scheme of connections is shown in Figure 101.

(b) When the compensating winding is connected in series with the armature winding, and the same current flows through both, the motor is said to be *conductively compensated.* If the compensating has

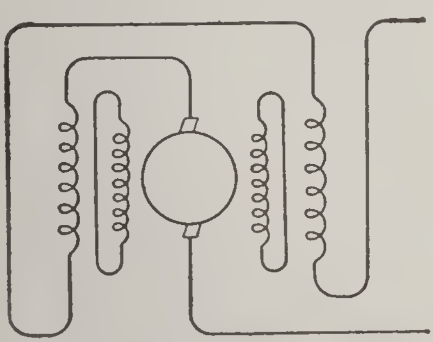


Fig. 101.

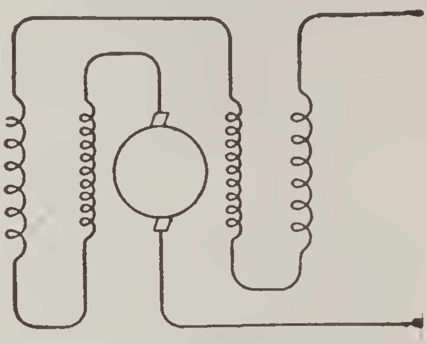


Fig. 102.

Figure 101.—Connection for Inductive Compensation. Fig. 102. Connection for Conductive Compensation.

the proper number of turns and the current is in the proper direction, the magnetic fields of the two windings tend to neutralize each other. A diagrammatic scheme of connections is shown in Figure 102.

Repulsion Motor.—If a direct-current armature be placed in a magnetic field produced by an alternating current, as indicated in Figure 103, there will be a transformer action taking place, the field winding acting as the primary and the armature winding as the secondary of the transformer. There will be a current between the short-circuited brushes for any position of the brushes on the commutator except the one shown in the figure. For the position of the brushes shown in the figure, the algebraic sum of the

electromotive forces induced in the coils in either of the circuits between the brushes is zero.

If the brushes be placed in the position shown in Figure 104, there will be a maximum current flowing

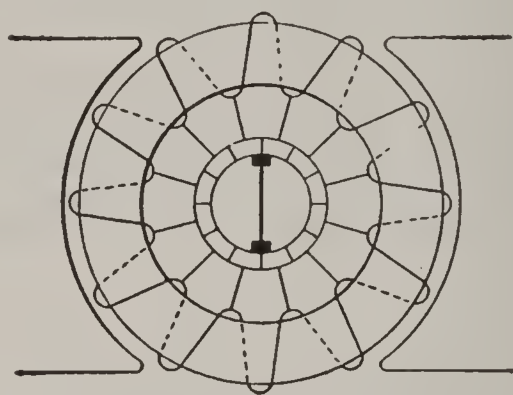


Figure 103.—Position of Short-Circuit Brushes for Zero Current.

between them. The magnetizing effect of this current in the armature is opposite to that of the current in the field windings and, as a result, the magnetic effect of the field windings is partly neutralized. When

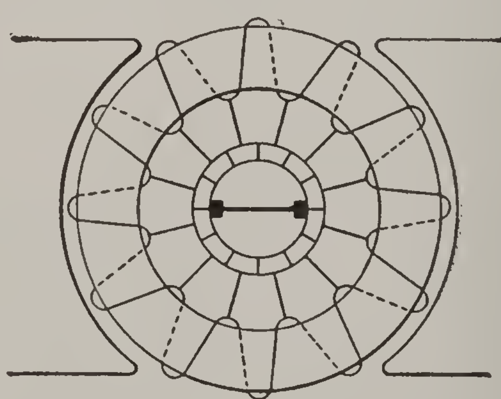


Figure 104.—Position of Short-Circuited Brushes for Maximum Current.

the brushes are in the position shown in Figure 103, there will be no resultant torque tending to produce rotation of the armature, as one-half of the inductors in each of the paths tend to produce rotation in one

direction and the remaining one-half tend to produce rotation in the opposite direction.

If the brushes be moved from the position shown in Figure 103, there is no longer zero resultant torque acting on the armature. The direction of rotation will depend upon the direction in which the brushes are moved with reference to the position shown in Figure 103. A motor operated in the above manner constitutes what is called a *repulsion motor*.

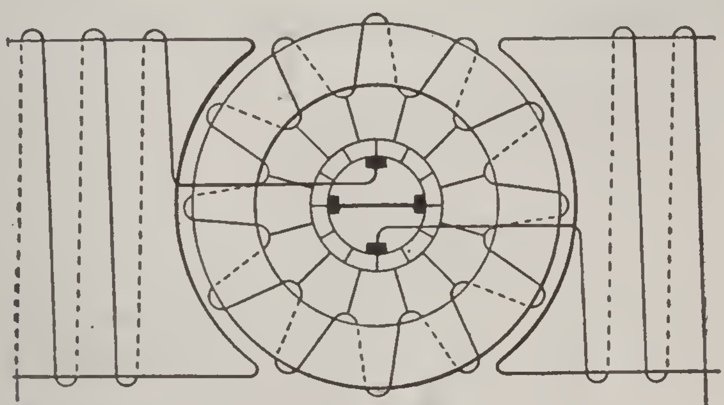


Figure 105.—Compensated Repulsion Motor.

Compensated Repulsion Motor.—The compensated repulsion motor is a series alternating-current motor with the addition of short-circuited brushes placed at right angles to the main brushes, as shown in Figure 105. The speed characteristic of this type of motor and its operation are quite different than either the series or the repulsion motor.

The magnetic effect of the current, due to the short-circuited brushes, counteracts to a great extent the magnetic effect of the main field winding. This current is produced by transformer action as in the repulsion motor when the brushes are in the position indicated in Figure 104.

The magnetic effect of the current between the

main brushes is at right angles to the main field or a line joining the short-circuited brushes, as shown in Figure 105. The current through the armature inductors, due to the short-circuited brushes reacting with the magnet flux produced by the main current, produces the larger part of the torque of the motor. Some torque, however, is doubtless produced by a reaction between the flux produced by the series field current and the current in the armature inductors between the main brushes. With an increase in speed, there is an increase in counter-electromotive force in

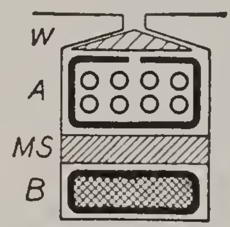


Figure 106.—Arrangement of Conductors in Slots of Wagner "BK" Motor.

the inductors, and the current between the short-circuited brushes becomes less and, hence, the torque is decreased. The speed characteristics of this motor are very similar to the direct-current shunt motor.

Combined Compensated Repulsion and Single-Phase Induction Motor.—One of the leading manufacturers of electrical machinery is making an alternating-current motor which is a combination of the compensated repulsion motor and the single-phase induction motor. The armature of this motor has two windings, a squirrel-cage and a commutated winding. The arrangement of these windings in one of the slots is shown in Figure 106. The electrical connections are indicated in Figure 107. There are currents produced in the commutated windings by transformer action

and these currents flow between the short-circuited brushes *5* and *6*. Currents are also inducted in the squirrel-cage winding. The current flowing between the main brushes of the commutated winding sets up a magnetic flux at right angles to that produced by the current in the winding *1*. The currents in the commutated winding between the short-circuited brushes and the current in the squirrel-cage windings

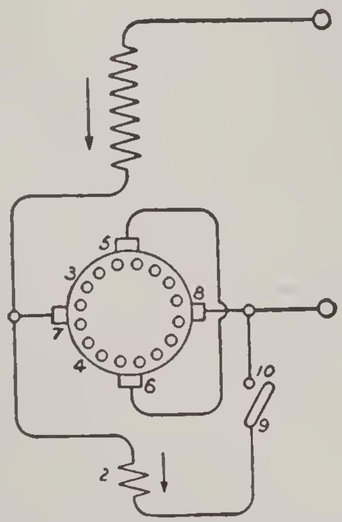


Figure 107.—Wiring Diagram of Wagner "BK" Motor.

react with this flux produced by the current between the main brushes and thus is produced a torque which starts the motor. With an increase in speed, there will be a magnetic flux produced by the current in the squirrel cage winding in quadrature with the current, and it develops a corresponding torque. The torque, due to the current between the short-circuited brushes, decreases with an increase in speed; and the torque, due to the current in the squirrel-cage winding, increases as synchronism is approached, as in the ordinary induction motor.

CHAPTER XI

METHODS OF STARTING, SPEED CONTROL, AND OPERATING CHARACTERISTICS OF ALTERNATING-CURRENT MOTORS

Methods of Starting Synchronous Motors.—If a single-phase alternator be electrically connected to alternating-current supply mains, the machine will not start up and run as a motor, unless it be first started and brought up to full speed by an engine, or other sources of power. This is due to the fact that the current in the armature of the machine is rapidly reversing in its direction, thus tending to turn the armature first in one direction and then in the other direction in rapid succession. Therefore, in the case of the single-phase synchronous motor, it is necessary that the power for starting it be supplied from a source independent of the single-phase supply, and that the motor be brought up to nearly the exact speed of synchronism with its alternator before it can be left to run on the current supplied to it.

Self-Starting of Polyphase Synchronous Motors.—On the other hand, if a polyphase alternator be connected to polyphase supply mains, the machine will start on this current and run up to full speed, provided it has little or no load. This self-starting feature of the polyphase machine is explained as follows:

The field circuit is to be left open while starting in this manner; only the armature is to be connected to the polyphase supply. As one of the phases of the

current passing through the armature dies away, it leaves a small amount of residual magnetism in the field-magnet structure, thus creating a rotating field such as is produced in the stator winding of an induction motor. This residual magnetism and rotating field act upon the growing current of the other phase, or phases, and produce a small starting torque, which will increase to a limited extent, especially if there is large armature reactance, which will be the case if a concentrated winding is used on the armature. The starting torque of the motor will also be greater when the motor is provided with a small air gap, than it will be if the air gap is large. A polyphase synchronous motor started in this way and running on open field circuit acts on the principle of an induction motor, and its speed gradually increases. When the speed is almost up to the speed of synchronism, the field switch may be closed, and if the motor now falls into step, the load may be thrown on.

The polyphase synchronous motor, when started in the manner just described, develops but little starting effort, the torque being barely sufficient to work it up to full speed with no load; therefore, it is generally started by means of an induction motor or a small engine. The larger sizes of polyphase synchronous motors are generally equipped with some such starting device, and when the motor is up to speed, and thrown into circuit, the load is gradually applied by means of a friction clutch. The smaller sizes are usually self-starting without load, the load being applied after the motor has reached synchronous speed.

This method of starting is objectionable, mainly because the machine takes excessively large lagging

currents at starting. This is liable to cause a drop in the supply voltage great enough to seriously disturb the general system of distributing mains from which the synchronous motor receives its supply current. If the motor is of such capacity as to require a large proportion of the generator output, or if the motor is used in connection with a lighting service, then the excessive demand for current at starting is especially objectionable.

Another serious objection to the self-starting of polyphase synchronous motors is the production of high voltages in the field coils, due to the fact that, at the time of starting, the armature and field windings of the motor are related to each other as are the primary and the secondary of an alternating-current transformer. The result is that when the field coils have many turns of wire, a dangerously high electromotive force may be induced in them and there is a liability of breaking down the insulation of the field coils. This may be avoided by using a few turns of large wire in the field winding, thus necessitating the use of a low voltage exciter. In this way, exciters giving electromotive force as low as 50 volts may be, and are frequently, used.

Another method is to provide short-circuited metal rings around the field poles. These rings limit the changes of magnetism in the pole pieces, and thereby prevent the formation of excessively high induced voltages in the field coils.

Starting Compensator.—This device, for a two-phase synchronous motor, consists of two transformers; and for a three-phase machine, three transformers are used. The transformers have their primaries connected across the respective phases of the supply

mains, while their secondaries are provided with a number of taps so that, at starting, a fraction of the full supply voltage can be applied to the armature terminals of the motor. This fraction is usually from 40 to 60 per cent of the full voltage. A switching

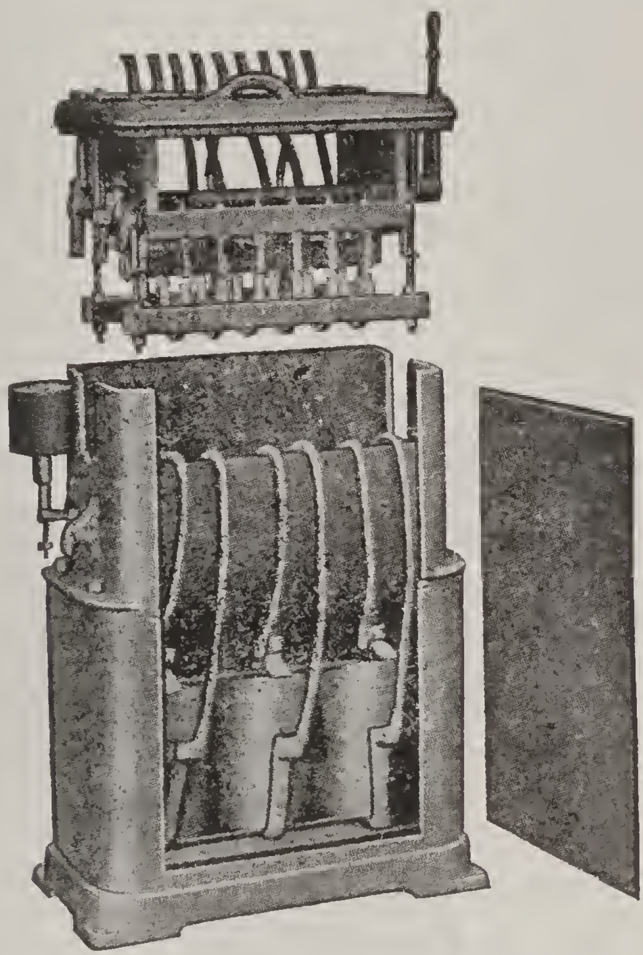


Figure 108.—Interior View of Floor Type Starting Compensator.

device is provided by means of which the change from fractional to full voltage can be quickly made when the motor reaches full speed.

In construction and operation the starting compensator resembles an auto transformer. Figure 108 shows an interior view of the starting compensator built by the Fort Wayne Electric Company, and may

be described as follows: An inductive winding, provided for each phase, is mounted on a separate leg of a branched magnetic core made up of laminated iron stampings. These windings and core, together with a cable clamp and switching mechanism, are

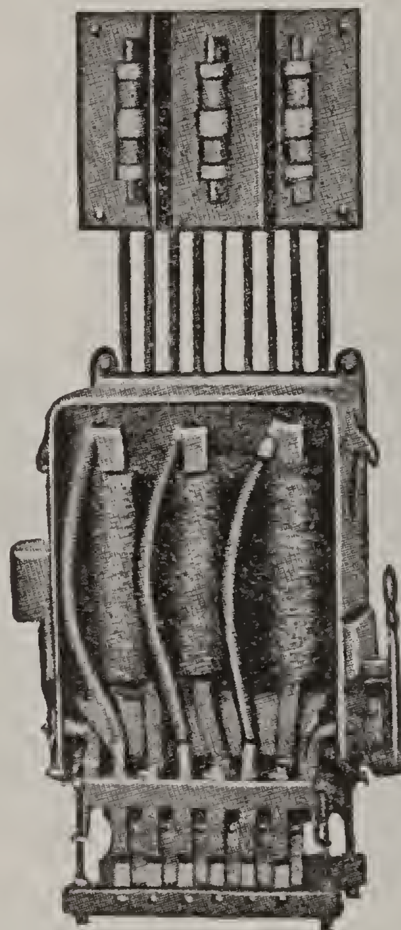


Figure 109.—Interior View of Wall Type Starting Compensator.

assembled in a case with external operating handle and release lever.

These compensators are built in six sizes, the first four sizes being the wall suspension type, and the remaining sizes the floor type shown in Figure 108. The wall type, an interior view of which is shown in

Figure 109, is made up in the following sizes: 60 cycle—5 to 200 horsepower; 40 cycle—5 to 135 horsepower; 25 cycle—5 to 100 horsepower. The larger capacities are built in the floor type, shown in Figure 108.

Each compensator is assembled in a metal case that is dust proof under ordinary conditions. In both types the covers may be readily removed for inspection of the interior or for changing the connections to alter the ratio of transformation. In the wall type compensator, the switch is located at the bottom, and the oil tank enclosing the switch may be removed separately for inspection, renewal of oil or contacts, etc., without taking the compensator down from the wall or disconnecting any of the leads. In the floor type, the switch is located in the upper part of the compensator casing and is equally accessible.

Windings of Compensators.—The inductive windings mentioned above are given a very thorough insulating treatment after being placed on the laminated core. They are placed in a large tank and baked under a high vacuum until every particle of moisture is driven out. An insulating compound is then introduced into the tank in a molten condition and forced into the coils under high pressure. This penetrating treatment fills every minute pore and, on solidifying, seals them in such a manner that it is absolutely impossible for moisture to enter. Besides making the windings moisture proof, this process gives a much greater mechanical stability to the coils.

Several taps are brought out from each coil, so that by connecting to the proper tap, the required starting current may be obtained to best suit each requirement. The particular tap is determined by trial at

the time of installation and the connections made permanent.

These taps provide for starting the motor at 80, 65, and 50 per cent of the line voltage with corresponding line currents of 65, 42, and 25 per cent of the current that would be taken by the motor if it were started direct from the mains. For larger motors, taps are provided to give a starting potential of 85, 70, 58, and 40 per cent of the line voltage, giving

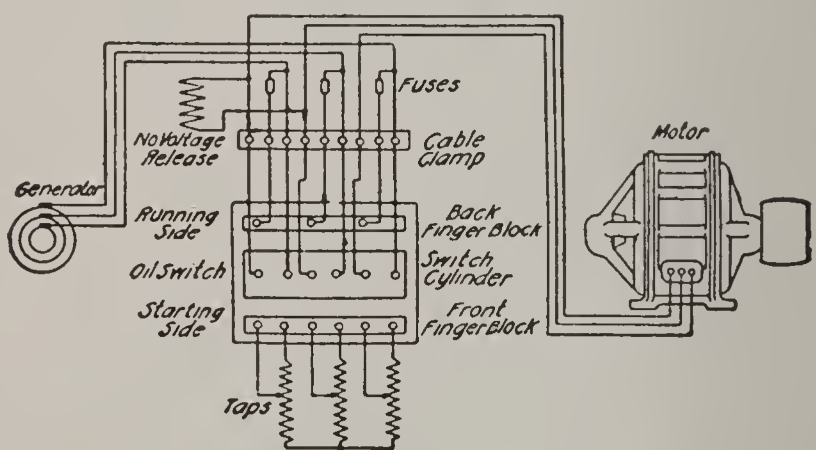


Figure 110.—Connections of Three-Phase Starting Compensator with No-Voltage Release.

respective currents equal to 72, 40, 34, and 16 per cent of the current that would be taken by the motor if no compensator were used. The three coils of the three phases are connected in Y, the line to the three free ends of the coil, and the starting connections of the motor to the taps, as shown in Figure 110.

In two-phase compensators, the line is connected to the ends of each coil, and the starting connections of the motors to the taps and the other ends.

The double-throw oil switch, provided with heavy wiping contacts within the compensator, is operated by a lever on the right of the case. The shaft of the

switch, to which the operating lever is attached, also extends through the case to the left, where a trigger holds it in the running position, Figure 108.

The starting lever has three positions: *Off*, *Starting*, and *Running*. In the off position, the lever stands vertically, with no connection existing between the motor and the line. Thus the compensator switch takes the place of the main line switch. In the starting position the line is connected to the terminals, and the motor to the taps of the compensator winding. In the running position, the compensator winding is cut out, and the motor is connected to the line fuses, or overload relays mounted above the compensator.

An automatic latch is arranged so that from *off* the lever can be thrown backward into the *starting* position; and thence forward into the *running* position only by a quick throw of the lever. This arrangement prevents the attendant from throwing the motor directly on the line, thereby causing a rush of current which it is the object of the compensator to avoid, and also eliminates any appreciable drop in speed, and consequent increase in current passing from the starting into the running position.

The compensators are designed for one-minute starting duty, and a tap should be chosen which will not give so low a voltage as to require over one minute for starting. This precaution is necessary to prevent over-heating, which is liable to happen to any starting device if carelessly handled. A strong spring prevents the switch from being left in the starting position.

The external lever is held in the running position until released either by hand or by the action of a no-voltage relay. This protective device consists of

a cast-iron frame, open at the bottom and totally enclosing the coil, so that it is neither exposed to damage in handling nor affected by foreign substances. A fiber piece covers the opening through which a laminated plunger connects with the tripping lever; this lever engages with the trigger on the switch shaft. Figures 110 to 113 show the connections of com-

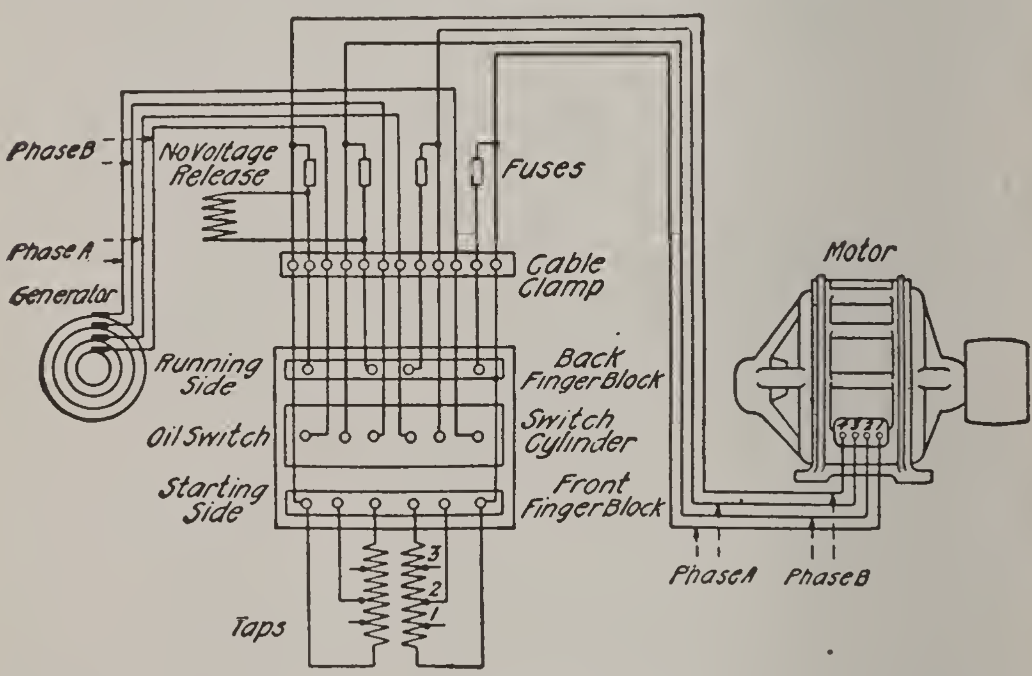


Figure 111.—Connections of Two-Phase Starting Compensator with No-Voltage Release.

pensators furnished with no-voltage release. Connections for the series-relay attachment are shown in Figures 112 and 113.

The overload relays are arranged to open the no-voltage relay circuit, allowing the laminated core to drop, and thereby releasing the switch. When properly adjusted, these relays have the advantage of protecting the motor against running single-phase, the increased load caused by the motor running single-phase being sufficient to trip the relay.

Relays furnished with compensators for 1040- to 2500-volt circuits are wound for 110 volts and consequently should be connected to some low tension circuit which would be affected in case of the failure of the voltage of the motor, or through a small transformer to the motor leads.

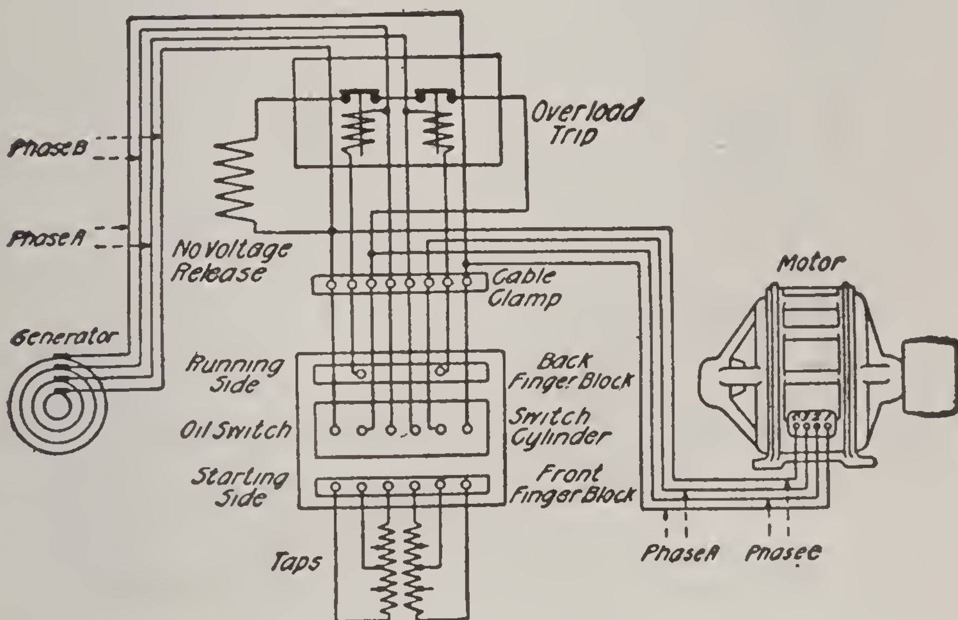


Figure 112.—Connections of Two-Phase Starting Compensator with No-Voltage and Overload Release.

In synchronous motors of the stationary field type, the field circuit may be broken up into many separate parts and brought out to convenient switches located on the front of the machine so as to divide up the induced electromotive force. While starting the motor, these switches are left open; and when the machine has reached synchronous speed, these switches are closed, thus connecting all the field coils in series with the exciter.

Speed Control of Synchronous Motors.—The speed of a synchronous motor, when it is operated on a cir-

cuit of constant frequency, is constant. If the load the motor is operating exceeds the capacity of the motor, the motor will stop, or *break down,* as it is called in practice, instead of merely decreasing in speed. The speed of a synchronous motor may be

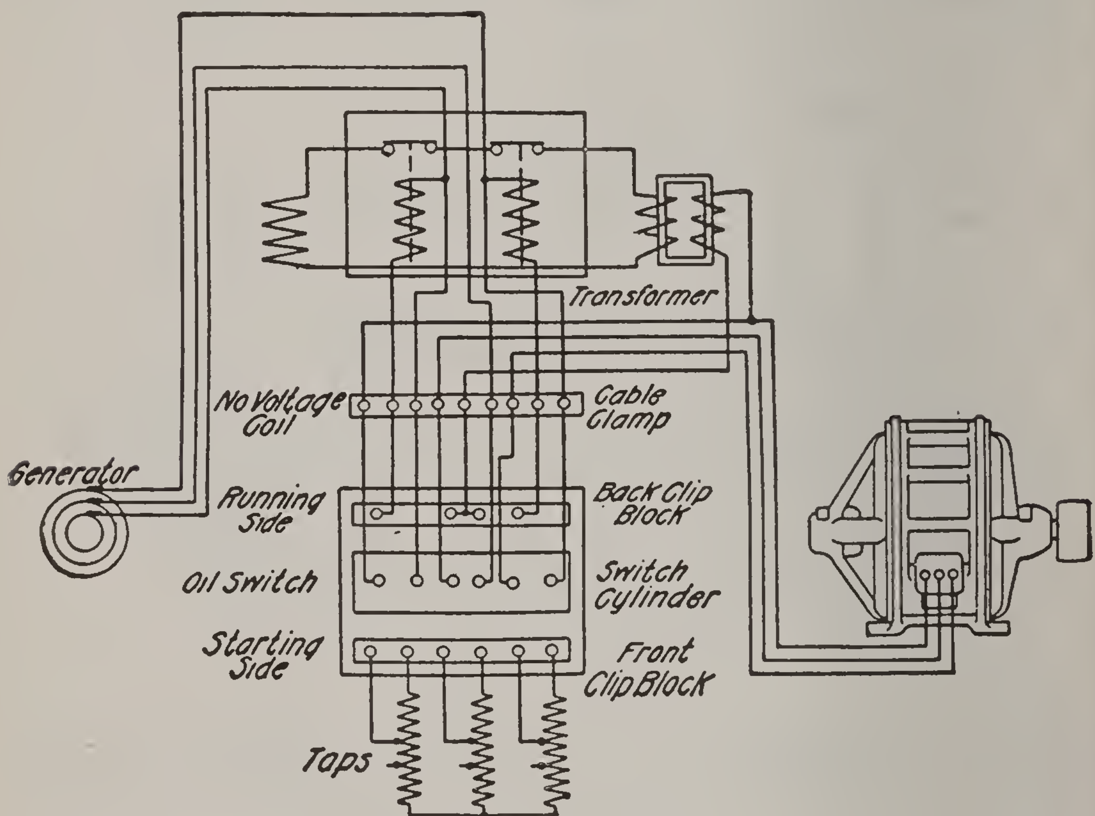


Figure 113.—Connections of Three-Phase Starting Compensator with No-Voltage and Overload Release and Transformer for High Voltages.

changed by changing the frequency of the supplied current, but this is little used.

Phase Characteristics of the Synchronous Motor.—The current required to operate a synchronous motor when it is driving a certain load, and the phase relation of this current and the impressed voltage, will depend upon the excitation of the motor. The phase characteristic of a synchronous motor is a curve show-

ing the relation between the armature current and the field excitation, the test being made under constant conditions with respect to voltage, frequency, and load. Phase characteristics are shown in Figure 114. Curve *A* corresponds to full load, curve *B* to one-half load, and curve *C* to light load.

Starting Single-Phase Induction Motors.—An induction motor designed to operate on single-phase current is called a *single-phase induction motor,* but it

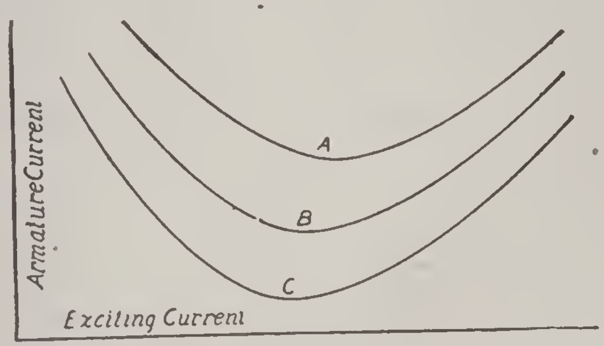


Figure 114.—Phase Characteristics of the Synchronous Motor.

will not start unless provided with some sort of a special starting arrangement. Four methods are in general use for starting single-phase motors. They are as follows:

(a) Hand starting
(b) Split-phase starting
(c) "Shading-coil" starting
(d) Repulsion motor starting

(a) *Hand Starting.*—Very small single-phase induction motors may be started by a vigorous pull on the belt connecting the motor to the driven machine.

(b) *Split-Phase Starting.*—By means of the proper arrangement of wiring, a single-phase alternating cur-

rent can be split into two parts and used exactly as a two-phase current is used. This is accomplished by allowing the single-phase current to divide itself between two branches of an auxiliary circuit in which the ratio of resistance to reactance is different in the two branches. This de-phasing of the two parts of a single-phase alternating current is called *phase splitting,* and, by taking advantage of this peculiarity of the alternating current, it is possible to obtain from a single-phase alternating current a two-phase current which can be utilized for starting a single-phase induction motor, provided the motor be arranged so as to start as a two-phase motor; and when the rotor has attained full speed, the auxiliary, or starting circuit, can be cut out of service, after which the motor continues to run at full rated speed on the single-phase current. Various methods and devices are in use by manufacturers of induction motors for accomplishing this result. In the single-phase induction motor built by the Holtzer-Cabot Electric Company, one set of stator coils, termed the *working coils,* consists of many turns of coarse wire, occupying three-fourths of all the stator slots; while the other set of stator coils, termed the *starting coils,* consists of fewer turns of fine wire, occupying one-fourth of all the slots. At starting, both sets of coils are connected to the single-phase supply mains, and the difference between the resistance and the reactance in the two sets of coils splits the single-phase current supplied sufficiently to create a rotary field similar to that produced in the regular two-phase motor. This gives a slight starting torque, which is sufficient, however, to turn the rotor, but not with any considerable load. Hence, the load, if it is difficult to start, should be

thrown on to the motor by means of a friction clutch after the rotor is running up to speed. The rotor used in the Holtzer-Cabot motor is of the squirrel-cage type.

Another starting device adapted only to the smaller sizes of single-phase induction motors consists of a condenser connected in series with one phase of the stator windings. This will give something near 90

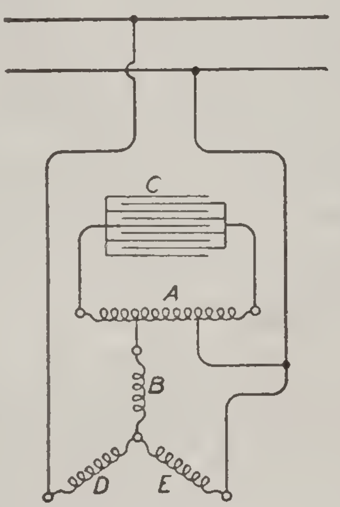


Figure 115.—"Split-Phase" Method of Starting Single-Phase Induction Motor.

degrees phase difference between the split-phase currents. This starting device, called a *condenser compensator,* and made by the General Electric Company, is provided with a small auto-transformer of the step-up type connected in shunt with the condenser. The fact that a condenser for a given volt-ampere capacity can be constructed much more cheaply for high than for low voltage led to the adoption of a step-up transformer, thus permitting the use of a condenser for high voltage electromotive forces.

Figure 115 shows the connections for this type of starting device for a single-phase induction motor. *A*

represents the auto-step-up transformer and C represents the condenser. The stator windings of the motor are represented by D and E, while the starting winding represented by B is connected to the junction of D and E. The motor is thus a three-phase motor at starting. When the rotor reaches full-rated speed, the starting winding B is cut out, and the winding DE then operates as a single-phase winding.

(c) *Shading-Coil Starting.*—Another starting device that is frequently used with small single-phase induction motors where the nature of the work is such that the load can be applied after the rotor is running up to speed, consists of what are termed *shading coils.* A shading coil consists of a single turn of copper placed in a slot cut in the pole face and bent around one side of the pole piece. The action of these shading coils is similar to the action of the secondary coil of a transformer in that its reactance upon the stator winding current tends to produce a distorted field, the result being similar to that obtained by a split-phase winding.

(d) *Repulsion Motor Starting.*—If an ordinary direct-current motor were provided with a laminated field magnet, and if its field magnet were excited by an alternating current, the result would be that currents would be induced in the armature windings, provided the brushes of the direct-current machine were set at an angle of about 45 degrees (for a two-pole machine) from their proper position for collecting a direct current. These currents induced in the armature would be acted upon by the alternating field in such a manner as to produce a torque that would cause the armature to revolve. A self-starting single-phase alternating-current motor constructed on this

principle is termed a *repulsion motor*. It is not entirely satisfactory in operation, but the repulsion-motor principle furnishes the best means for making a single-phase motor self-starting; that is, a motor designed and constructed in such a manner that it can act as a repulsion motor while starting, and which, by changing certain inside connections, can be altered into an induction motor when it reaches full speed.

Starting Polyphase Induction Motors.—In order that a polyphase induction motor may not take an excessive current from the circuit to which it is connected when the motor is starting, either a resistance must be placed in the rotor circuit or the voltage impressed on the primary must be reduced. There are two general methods of starting polyphase induction motors, as follows:

(a) Pressure method of starting.
(b) Rheostatic method of starting.

(a) The pressure method of starting consists of reducing and regulating the voltage impressed upon the primary of the motor by means of a compensator or auto-transformer.

(b) The rheostatic method of starting makes use of the fact that a much greater torque can be produced by a given current when there is an extra resistance in series with the stator winding. This resistance in some small machines is located inside the rotor and is cut out of the circuit automatically as the machine speeds up. The resistance, however, is usually outside of the rotor and connected in circuit with the rotor winding by means of collector rings and brushes.

Reversing Induction Motors.—A single-phase motor will run in either direction equally well, depending

only upon the direction in which it is started. A hand started motor, therefore, can be started in either direction. The direction of motion of a split-phase motor may be reversed by reversing the connections of the starting winding. The direction of rotation of a two-phase motor may be reversed by reversing the connections of the two wires of either phase. To reverse the running direction of a three-phase motor, it is only necessary to change any two of the phase wires.

Speed Control of Induction Motors.—The speed of an induction motor may be controlled in five different ways, as follows:

(a) By varying the pressure applied to the primary winding.
(b) By varying the resistance in the secondary winding.
(c) By changing the number of poles.
(d) By varying the frequency of the applied pressure.
(e) By connecting the secondary of one motor to the primary of another motor.

(a) The speed control of an induction motor, by varying the pressure applied to the primary, is an elaboration of the pressure method of starting.

(b) The speed control of an induction motor, by placing a resistance in the secondary circuit, is an elaboration of the rheostatic method of starting.

(c) By properly designing the windings, an induction motor may have its number of poles changed by means of a throw-over switch to which the different taps of the winding are connected.

(d) Currents of different frequencies may be supplied from two different generators and the motors operated on one or the other of these circuits as the demands in speed may require.

(e) If the two motors are rigidly connected to a common shaft, their speed may be controlled by con-

necting the secondary of the first motor to the primary of the second motor, and the controlling resistance in the secondary of the second motor, the primary of the first motor being connected to the line. This method of speed control is called the *concatenation,* or cascade, control. The speed of the shaft to which the motors are connected may be that of either motor acting alone, or it may be that of the two motors in direct or differential concatenation. Let p_1 represent the number of poles on one motor, p_2 the number of poles on the other motor, and f the frequency of the supplied current. The speed of the shaft may have any one of the following four values:

Number one alone $$S = \frac{120 \times f}{p_1}$$

Number two alone $$S = \frac{120 \times f}{p_2}$$

Direct concatenation $$S = \frac{120 \times f}{p_1 + p_2}$$

Differential concatenation $$S = \frac{120 \times f}{p_1 - p_2}$$

Operating Characteristics of the Induction Motor.—speed of the induction motor decreases in value with an increase in load very much like the direct-current shunt motor. The current taken by the motor will increase with an increase in load and the increase in the current becomes more rapid near full- or over-loads. The power factor increases very rapidly for low loads and should reach a maximum value near full load.

CHAPTER XII

CARE AND OPERATION OF ALTERNATING-CURRENT MOTORS, AND ALTERNATING-CURRENT MOTOR TROUBLES

Location.—Motors should be located in clean, dry, well-ventilated and easily accessible places, free from acid fumes, steam, dripping water, or oil, and excessively high temperatures. If the conditions under which the motor is to be operated are unusual and do not comply with the above-mentioned requirements, it is best to install motors of a special construction adapted to the situation.

Foundations.—The foundation should be sufficiently solid to prevent excessive vibration. Masonry or concrete is to be preferred, but wood frame work or timber can be used. Wall or ceiling supports should be rigid.

Erection.—The motor shaft should be level, or, if the motor is of the vertical type, the shaft should stand exactly perpendicular. If the motor is geared, the gears should mesh properly; if direct connected, the motor shaft and driven shaft must be in line, except for a slight variation permissible with flexible couplings.

If a belt is used for transmitting power from the motor to the driven shaft, the driving and driven pulleys should be aligned properly, so that the belt will run true. Bolt the slide rails or bed plate securely to the foundation and bolt the motor to the slide rails

or bed plate. Key the pulley to the shaft and tighten the screw firmly. Turn the armature, in order to see that the pulley hub does not strike the bearing housing, then put on the belt and tighten it by moving the motor by adjusting the belt adjusting screw. The belt should be run with, not against, the belt lapping and should drive on the lower side.

Wall or Ceiling Mounting.—With motors provided with oil reservoirs, the brackets should be turned through 90 or 180 degrees, in order to keep the oil reservoirs directly under the shaft.

Bearings.—If the bearings overheat, the causes may be one or more of the following:

(a) Excessive belt tension.
(b) Defective lubrication, due to either a poor grade or insufficient quantity of lubricating oil, or failure of the oil rings to revolve.
(c) Incorrect aligning or leveling, thereby causing excessive end thrust, or binding.
(d) A rough bearing surface.
(e) Bent shaft.

If a bearing becomes hot, first slacken the belt, then feed a heavy lubricant copiously. If relief is not thus afforded, shut down the motor, keeping the armature or rotor slowly revolving until the bearing is cool, in order to prevent the bearing from sticking or "freezing."

Lubrication.—Before starting a motor, fill the oil reservoirs with the best quality of clean dynamo oil. Overflow plugs, if present, should always be kept open. Old oil should be withdrawn occasionally, and fresh oil substituted, the intervals of time for doing this depending upon the nature of the service the machine is performing. The old oil can be filtered and

used again. If the oil is fed to the bearings by wicks, or oil feeding cups, the drip of oil from the bearings will show that they are in order. Ring oiling is much used at present and is, in fact, much more reliable than other systems, but the rings should be watched to see if they move properly around the journals.

These rings are several times the diameter of the journal or axle and hang upon it, their lower portions dipping into the oil reservoir in the lower portion of the bearing housing. As the shaft revolves, they travel around it, thus carrying oil to the upper surface of the journal. When cleaning out the old oil and before adding new oil, the oil reservoirs should be washed out with kerosene oil. A small syringe is very useful for this purpose. Oil should be carefully kept off the brush holders, commutator surface, and the winding of armature and field.

Safety Fuses.—These should be inspected at frequent intervals to see if they are tightly screwed down or clamped, and also if their contact faces are clean.

Insulation.—A careful watch should be made for bare spots or weak spots on the insulation of all wires in the windings. If there are any indications of such defects, they should be immediately taped or insulated in some way.

Broken Wires.—A broken wire can be detected by the feeling, even if it is thickly insulated, by slightly bending or moving the wire. If there are any indications of burning or overheating of the insulation, a fracture of the wire may be suspected at that point.

Soldering Wires.—Acid should never be used in soldering wires together. For this purpose, anti-corrosive soldering fluxes may be procured, which can be

used on iron or copper, and will answer the purpose as well as acid, and thus eliminate any bad after effects of corrosion due to the use of acid.

Idle Motors.—When a motor is doing no work, the current should be cut off. A motor running without load draws energy from the circuit which must be paid for.

Collector Rings.—The collector rings on alternating-current machines should be kept bright and clean. A little vaseline applied from time to time is good practice. If the surface is rough, the machine should be stopped, the brushes lifted off, the armature or rotor started turning again, and the rings be sandpapered, using a hollowed block of wood to hold the sandpaper.

Local Heating of Stator Windings.—This, in an induction motor, indicates a double short-circuit, either in a single coil or in two neighboring coils. If wound for *Y* distribution, an interruption of one phase will interfere with the running of the machine. If the load is light, the motor may go on as a synchronous motor. Sometimes the beginning and end of a coil are interchanged in their connection, so as to reduce the phase difference to 60 degrees. This interferes with the running of a three-phase *Y*-connected motor.

If one phase of the primary is open, the motor will not start and the current will be unbalanced.

If one phase of the primary is reversed, the current will be very much unbalanced when the motor is running, and there will be very little starting torque.

Induction-Motor Rotors.—The short-circuited self-contained rotor of the modern induction motor seldom gives trouble. In the older types, the rotor would

sometimes become so hot as to melt the solder on the winding connections, thus opening the circuit and causing the machine to stop. Good modern practice uses no solder on the connections, but, by hard metal couplings or brazing, secures heat-proof joints.

If the secondary winding of the motor is open, the motor will not start and it will not take a current greater than the exciting current.

If one phase of the secondary winding is open, the motor has a tendency to operate at one-half speed, although the current may be apparently normal. If the current in the three phases is measured, when the rotor is blocked, it will be found unbalanced.

Starting and Speed Regulation.—Synchronous motors, whether single-phase or polyphase, should be speeded up before the load is thrown on, and this should be gradually applied only when full speed is attained. If overloaded, the motor will stop. This type of motor will maintain a constant speed (synchronous) and will run at no other.

Polyphase induction motors which can carry an overload within certain limits, lose in speed as the load is increased, but are self-starting, even with a load.

Cleaning a Machine.—Cotton waste should be carefully used in cleaning a motor or generator, as threads from it will catch in and stick to the commutator and other surfaces. Dust can be blown out of inaccessible places with a hand bellows, or, in case compressed air is available, a small air hose can be used.

Starting Induction Motors.—Small size induction motors—3 to 5 h p.—may be started by connecting the stator terminals directly to the line, but with the larger sizes the inrush of current is excessive, and a starting compensator, or some other form of starting

device, is usually necessary in order to prevent too great a disturbance of the system.

Speed Regulation for Induction Motors.—For some classes of work, it is desirable to arrange induction motors in such a manner that their speed can be controlled, the usual methods being either the insertion of a variable resistance in the rotor circuit or cutting down the voltage of the current applied to the stator windings. Both methods are explained in another section of this book.

A two- or three-phase induction motor will operate fairly well, if, after it has reached full speed, all but one of the phases be cut out. It will not, however, start from rest with only single-phase excitation.

Safety Precautions.—Keep all tools and pieces of iron or steel away from the machine while running, as they might be drawn in by the magnetism and perhaps get between the rotor and stator, and thus ruin the machine. For this reason it is safest to use a zinc, brass, or copper oil can, instead of one of iron or "tinned" iron. Never allow your body to form part of a circuit. While handling a conductor, a second contact may be accidentally made through the feet, hands, knees, or other part of the body, in some unexpected manner, the result being fatal. Rubber gloves or rubber shoes, or both, should be worn when handling circuits of over 500 volts. The safest plan is not to touch any conductor carrying a current. Tools with insulated handles, or a dry stick of wood, should be used instead of the bare hands. If possible, use only one hand when handling dangerous conductors, because by so doing there is not so much danger of getting the current through the body. The rule, *keep one hand in your pocket,* is a good rule to remember

when working around electric machines or highly charged circuits. Short-circuits between armature windings and frame are dangerous not only to the machine but to the life of the attendant if a grounded circuit is on the line. A 110-volt current has killed in several recorded cases. A good practice is to ground the frame of an alternating-current machine; then if a man touches the frame of a machine in which a dangerous short-circuit exists, he is simply in parallel with a portion of the frame and receives no injury. Were the frame not grounded, the man might be killed. If no ground circuit exists on the line, such a contact of windings and frame may remain undiscovered indefinitely, unless closely watched for. It is a good plan to inspect and test the machines at intervals for the purpose of ascertaining if such dangerous conditions actually exist, and, if so, to remedy them.

TABLE I

Specific Resistance, Temperature Coefficient, Percent Relative Resistance and Conductance of Different Materials

Material	Measurements at 0° Centigrade			Relative Resistance %	Relative Cond %	Temperature Coefficient	
	Michroms per cub. cm	Michroms per cub. inch	Mil — foot resistance			Centigrade	Fahrenheit
Copper (Matthiessens Standard)	1.594	.6272	9.54	100.0	100.0	.00420	.00233
Copper Annealed	1.56	.614	9.35	97.5	102.6	.00428	.00242
Silver	1.47	.579	8.82	92.5	108.2	.00400	.00222
Zinc (pure)	5.75	2.26	34.5	362.	27.6	.00406	.00226
Iron (very pure)	9.07	3.57	54.5	570.	17.6	.00625	.00347
Lead (pure)	20.4	8.04	123.	1280.	7.82	.00411	.00228
Platinum (annealed)	8.98	3.53	53.9	565.	17.17	.00247	.00137
Mercury	94.3	37.1	566.	5930.	1.69	.00072	.00044
Gold (practically pure)	2.2	.865	13.2	138.	72.5	.00377	.00210
Aluminum (99% pure)	2.6	1.01	15.4	161.	62.1	.00423	.00235

TABLE II

COPPER WIRE TABLE

Working Table, International Standard Annealed Copper

American Wire Gage (B. & S.)

Gage No.	Diameter in Mils	Cross Section		Ohms per 1000 Feet		Pounds per 1000 Feet
		Circular Mils	Square Inches	25° C (=77° F)	65° C (=149° F)	
0000	460.	212 000.	0.166	0.0500	0.0577	641.
000	410.	168 000.	.132	.0630	.0727	508.
00	365.	133 000.	.105	.0795	.0917	403.
0	325.	106 000.	.0829	.100	.116	319.
1	289.	83 700.	.0657	.126	.146	253.
2	258.	66 400.	.0521	.159	.184	201.
3	229.	52 600.	.0413	.201	.232	159.
4	204.	41 700.	.0328	.253	.292	126.
5	182.	33 100.	.0260	.319	.369	100.
6	162.	26 300.	.0206	.403	.465	79.5
7	144.	20 800.	.0164	.508	.586	63.0
8	128.	16 500.	.0130	.641	.739	50.0
9	114.	13 100.	.0103	.808	.932	39.6
10	102.	10 400.	.008 15	1.02	1.18	31.4
11	91.	8230.	.006 47	1.28	1.48	24.9
12	81.	6530.	.005 13	1.62	1.87	19.8
13	72.	5180.	.004 07	2.04	2.36	15.7
14	64.	4110.	.003 23	2.58	2.97	12.4
15	57.	3260.	.002 56	3.25	3.75	9.86
16	51.	2580.	.002 03	4.09	4.73	7.82
17	45.	2050.	.001 61	5.16	5.96	6.20
18	40.	1620.	.001 28	6.51	7.51	4.92
19	36.	1290.	.001 01	8.21	9.48	3.90
20	32.	1020.	.000 802	10.4	11.9	3.09

Gage No.	Diameter in Mils	Cross Section		Ohms per 1000 Feet		Pounds per 1000 Feet
		Circular Mils	Square Inches	25° C (=77° F)	65° C (=149° F)	
21	28.5	810.	.000 636	13.1	15.1	2.45
22	25.3	642.	.000 505	16.5	19.0	1.94
23	22.6	509.	.000 400	20.8	24.0	1.54
24	20.1	404.	.000 317	26.2	30.2	1.22
25	17.9	320.	.000 252	33.0	38.1	0.970
26	15.9	254.	.000 200	41.6	48.0	.769
27	14.2	202.	.000 158	52.5	60.6	.610
28	12.6	160.	.000 126	66.2	76.4	.484
29	11.3	127.	.000 099 5	83.4	96.3	.384
30	10.0	101.	.000 078 9	105.	121.	.304
31	8.9	79.7	.000 062 6	133.	153.	.241
32	8.0	63.2	.000 049 6	167.	193.	.191
33	7.1	50.1	.000 039 4	211.	243.	.152
34	6.3	39.8	.000 031 2	266.	307.	.120
35	5.6	31.5	.000 024 8	335.	387.	.0954
36	5.0	25.0	.000 019 6	423.	488.	.0757
37	4.5	19.8	.000 015 6	533.	616.	.0600
38	4.0	15.7	.000 012 3	673.	776.	.0476
39	3.5	12.5	.000 009 8	848.	979.	.0377
40	3.1	9.9	.000 007 8	1070.	1230.	.0299

NOTE—The table is based on the international standard of resistance for copper, which takes the fundamental mass resistivity = 0.15328 ohm (meter, gram) at 20° C, the corresponding temperature coefficient = 0.00393 at 20° C, and the density = 8.89 grams per cc at 20° C. The temperature coefficient is proportional to the conductivity, whence the change of mass resistivity per degree C is a constant, 0.000597 ohm (meter, gram).

NOTE 2—The values given in the table are only for annealed copper of the standard resistivity. The user of the table must apply the proper correction for copper of any other resistivity. Hard-drawn copper may be taken as about 2.7 per cent higher resistivity than annealed copper.

NOTE 3—Ohms per mile, or pounds per mile, may be obtained by multiplying the respective values above by 5.28.

NOTE 4—For complete tables and other data see Circular No. 31 of the Bureau of Standards.

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D

ELECTRICAL OPERATING AND TESTING

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CHAPTER I

THE ELECTRIC CURRENT

By the electric current is meant that agency which comes into action when a circuit containing an electro-motive force is closed. Electro-motive force is, as the name implies, the impelling force, and the circuit is the system of conductors along which alone electrical action takes place. This flow of current is quite analogous to the flow of water in a system of piping or over the surface of the earth. Such a flow of water can take place only when the water is at different levels, or, when from any cause, a difference of pressure exists between different points. When either or both of these conditions exist the flow always takes place in a certain direction, i. e., from the high level or pressure to the lower, and this flow is always more or less diminished by obstacles or resistances. The same observations hold true of electric currents; they flow only in obedience to electrical pressure; they flow always in a certain direction determined by that pressure and the quantity of the flow depends, or is governed, other things being equal, by obstacles which are spoken of as resistances.

We cannot prove, and it is not necessary, that there is any actual direction, or, much less, a change of direc-

tion, or even a flow of current, but the phenomena noticed make the assumption a very convenient one and it is, to say the least, very helpful in the study and application of these phenomena.

Refer now to Figure 1 which shows a common glass jar nearly filled with water and which also contains a small quantity of sulphuric acid and one plate of zinc Z and another of copper C. While the two ends of the wires connected to the plates remain apart there is no flow of current, but an electrical pressure

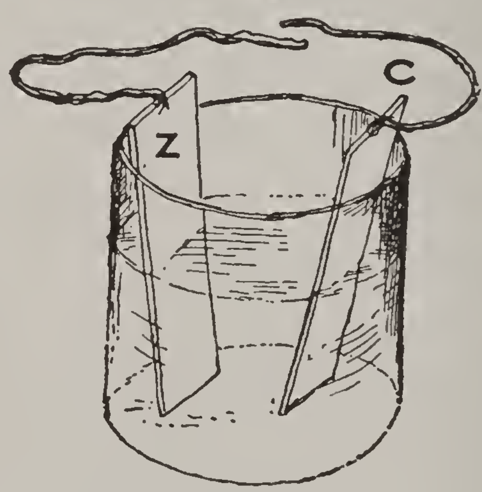


Figure 1

exists, as can readily be shown. As soon, however, as we bring the two ends of wire together a flow of current takes place. It is the high resistance of the air between the two terminals of the wires which prevents the flow of current in this case, just as the resistance of the valve in a water pipe prevents the flow of water when it is closed.

The direction of the flow of current is said to be from the zinc to the copper inside of the cell and from the copper back to the zinc in the exterior circuit or

outside of the cell. In all batteries (a battery is a number of cells coupled together) the copper plate or terminal is spoken of as the positive or + pole from which the current flows and the zinc plate as the negative or — pole toward which the current flows. From the cell shown, which is the simplest of all forms, we

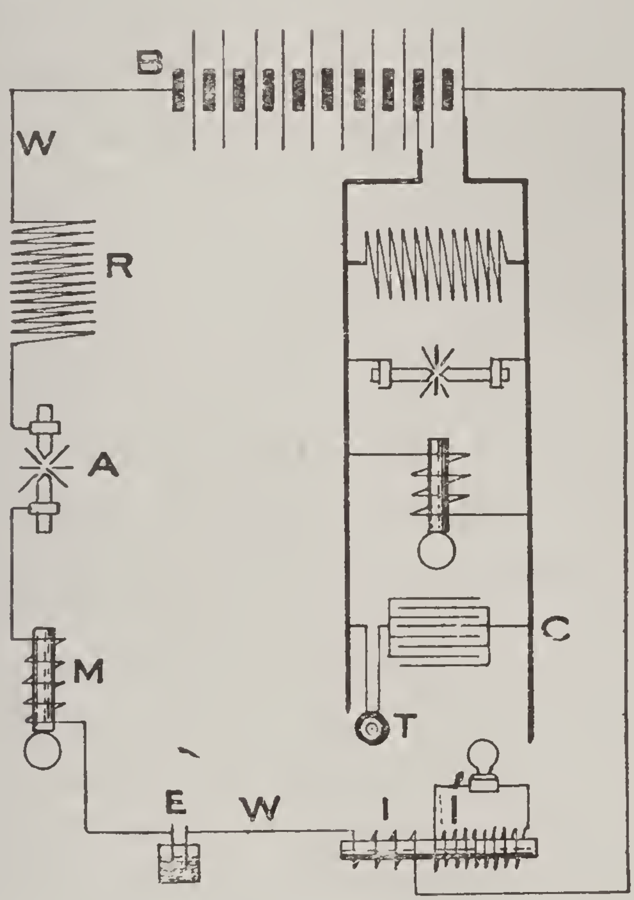


Figure 2

can obtain but a very insignificant current, and that for only a very short time, for reasons to be given later on. If we couple a number of cells together, as conventionally indicated at B in Figure 2, we shall be able to obtain a considerable current. In this representation of a battery the long thin lines stand for the copper plate from which the current flows to the

outside circuit and the short thick lines stand for the zinc element from which the current flows inside of the cell to the copper element.

Figure 2 has been drawn principally to acquaint the reader with the general effects obtainable from the electric current. In the outer system of wires W, W, etc., the same current passes through all of the devices, and this is known as a series circuit. R represents fine wire, which will be heated to redness or even melted if the current is made strong enough. At A is shown the manner in which an arc or a flash may be produced; first bring the ends of carbon or metal together until the current is started, then separate them a little and the current will continue, thus forming a very hot flame known as the electric arc.

If a wire carrying a current be wound about an iron core M, magnetism will be generated and enable the iron bar to attract other pieces of iron. This magnetism will exist only while the current is flowing.

If the current is forced to pass through water, as indicated at E, it will decompose it and this decomposition will be noticeable by the bubbles of gas given off. If the current pass through a suitably prepared bath in which metals are properly connected to the wires, the metal will be eaten away from the positive pole and deposited at the negative.

The arrangement of wires shown at I, I^1 is drawn to illustrate the method of inducing currents of electricity in transformers. When a current is passed around the bar at I a current will be induced in I′. This current will last only a very short time, but if I is connected to a circuit in which the current is contin-

ually changing in value the induction of currents will follow every change in current strength and it is possible to arrange these variations in such a manner that light may be obtained from these induced currents.

The inner circuit shown connected to the battery by heavy lines is known as a parallel circuit, all of the devices being connected in parallel instead of in series as in the other. In such a circuit each device is independent of the others and the current increases in proportion to the needs of the devices connected. The more there are connected the greater becomes the current, but the voltage need not be increased. In a series circuit the more devices there are connected the more cells of battery must be provided to increase the pressure so that the current may remain the same. Only such devices as use the same amount of current can be run in a series circuit.

In the parallel circuit at C there is shown a condenser. A condenser is an arrangement of plates which is capable of taking a charge of electricity at rest much as a jar is capable of taking a charge of water. The positive and negative plates of a condenser are perfectly insulated from each other and a current of electricity cannot pass from one to the other. When, however, the plates are connected to a source of current a small quantity of current will pass into the condenser. Such a charge may be held in a condenser for some time or will pass out of it when the voltage at the terminals is withdrawn or the circuit around the condenser closed. Enough current can be made to pass in and out of a small condenser to affect a telephone receiver T, or a sensitive polarized bell.

CONDUCTORS AND INSULATORS

An appreciable current flow can take place only in a system of electrical conductors. The best conductors are the various metals in the order here given: silver, copper, gold, platinum, tin, lead, etc. The difference in favor of silver as against copper is so small compared to the higher price of silver that the latter is seldom used. A pound of copper will, under the same circumstances, carry about 6 or 7 times as much current as a pound of iron and as this fact makes copper much cheaper than iron, copper is the metal almost universally used for electrical purposes.

It is not, however, sufficient to provide conductors along which the current can flow; it is also necessary to surround these conductors with some material which will prevent the current from flowing anywhere except along these conductors. A bare copper wire lying on some other conducting material can no more be depended upon to carry the current than a lot of broken or disconnected pipes can be depended upon to carry a stream of water. Even under such conditions the current may flow along the wires and the water may flow along the pipes if these happen to offer the easiest path, but in neither case will it be possible to get any work done. To get the proper service from either we must be able to force the flow where our machinery needs it; whatever portion of it we can not so confine is a direct loss.

Such materials as resist the flow of current sufficiently to prevent its escape from the conductors in appreciable quantities are known as insulators. Some

of them are: air, glass, silk, rubber, dry asbestos, porcelain, slate, marble, wood, mica, shellac, paraffine, etc. All insulators to give the best service require to be dry. If they are wet current will leak through the body of those that are porous and over the surface of those that are not. It should be borne in mind that there is no such thing as, either a perfect conductor or a perfect insulator. Every conductor offers some resistance to the flow of current and no matter what the insulator may consist of, if we but make the pressure great enough we can force some current through it.

CHAPTER II

ELECTRICAL UNITS

In order to make any practical use of electricity we must be able to measure it, and for the purpose of measurement and calculation the following units have been adopted by electricians, and in turn legalized by the U. S. government:

The *ohm* as the unit of resistance.

The *ampere* as the unit of current flow or current strength.

The *volt* as the unit of electro-motive-force or electrical pressure.

The *coulomb* as the unit of quantity.

The *farad* as the unit of capacity.

The *joule* as the unit of work.

The *watt* as the unit of power.

The *henry* as the unit of induction.

THE OHM

The ohm is the unit of resistance. Resistance is a property possessed by all materials, but in varying degrees. It always varies inversely as the cross-section of the material; that is, the larger the wire the less will be its resistance and the smaller the wire the

greater will be its resistance. The resistance of all materials increases directly as the length, and is, also, to a small extent, affected by a rise in temperature. This resistance acts electrically much as friction does mechanically; it is very useful in the proper place and very objectionable in the wrong place. It is this resistance in the filament of a lamp that gives us light when current is forced through it, and heat in the heater, but it is also this resistance which causes the loss in voltage or pressure which makes it so difficult to transmit currents of magnitude over wide areas. Resistance tends to diminish current flow and, when great enough, prevents it entirely.

The legal ohm is equivalent to the resistance of a column of mercury 106.3 centimeters long, 14.4521 grammes in mass and at the temperature of melting ice. As an illustration of more practical value: 2 3/10 feet of No. 36 B. & S. gauge wire has a resistance of one ohm; 380 feet of No. 14 wire a resistance of one ohm and 1,000 feet of No. 10 wire a resistance of one ohm.

THE AMPERE

The ampere is the unit of current strength. It expresses the rate of current flow. It is not correct to speak of it as measuring quantity. To obtain the quantity we must multiply the amperes flowing by the length of time they flow. The heating of a wire, the chemical action and the magnetism produced are all due to the amperes flowing in the circuit. The legal ampere is that current, which, when passed through a solution of nitrate of silver, prepared in accordance

with certain specifications, deposits silver at the rate of 0.001118 grammes per second.

It is the current which results from a pressure of one volt acting in a closed circuit on a resistance of one ohm. A 16 c. p. 110 volt incandescent lamp requires a current of one-half ampere; an open, series arc lamp a current of about 10 amperes.

THE VOLT

The volt is the unit of electro-motive-force, or electrical pressure. It is this pressure which is the immediate cause of current flow and we speak of it as of so many volts, just as we speak of steam pressure as of so many pounds.

The volt is defined as the electro-motive-force which will force a current of one ampere through a resistance of one ohm. This is equal to about 1000/1434 of the electro-motive-force of a Clarkes cell. The common wet carbon battery gives about 1.2 volts; a storage battery about 2 volts per cell.

THE COULOMB

The coulomb is the unit of quantity. It is the current delivered by one ampere in a second. To find the number of coulombs we multiply the number of amperes by the time in seconds. This unit is seldom used.

THE FARAD

The farad is the unit of capacity. Under certain circumstances electrical conductors and certain appliances chiefly known as condensers can be heavily charged with static electricity (electricity in a state of rest) and can be again discharged; and, in fact if

subjected to an alternating electro-motive-force this charging and discharging is continually taking place. This charge depends upon the nature of the material out of which the condenser is made upon the number and size of the plates and upon the electro-motive-force of the circuit. The more current there is forced into a given condenser the greater will be its potential difference. This can not, of course, be greater than that maintained at its terminals unless a static charge be given.

Such a conductor or condenser is said to have a capacity of one farad, when a charge of one coulomb produces a difference of potential of one volt. This unit comes into use very seldom in ordinary work.

THE JOULE

The joule is the unit of work. It is equal to the energy expended in forcing one ampere through a resistance of one ohm, in one second. This unit is also seldom used.

THE WATT

The watt is the unit of power. Just as the ampere expresses the rate of current flow, without telling us anything about the actual quantity delivered, so the watt measures the rate of doing work, or the rate of energy consumption in the circuit. The watts in any circuit are equal to the volts multiplied by the amperes. An incandescent lamp requiring 110 volts and ½ ampere is said to consume energy at the rate of 55 watts. Seven hundred and forty-six watts equal one horsepower. The watt is a much used unit and charges for use of light or power are usually based

upon watt-hours. The watts supplied, multiplied by the time, measure the power delivered.

THE HENRY

The henry is the unit of induction. It is seldom used in ordinary practical calculations but an understanding of its meaning is important.

The henry represents the induction in the circuit when the induced electro-motive-force is equal to one volt while the inducing current varies at the rate of one ampere per second.

CHAPTER III

MAGNETISM

The simplest form of magnet and also the one with which people are most familiar is the compass needle. This needle is merely a bit of magnetized steel and has the property of pointing toward the north with one of its ends and, of course, south with the other. Such a compass needle is a very convenient instrument to have about and many instructive little experiments can be made with it. If we take a compass and explore any piece of steel that has been lying in a north and south direction, as, for instance some portion of a steel building, we shall quickly see that the north end of the piece of steel has a tendency to repel the north seeking end of the needle, but will attract the south seeking end of the same needle with as much force as it repelled the other end. In making this experiment and in all other similar experiments care must be exercised not to bring the needle, especially if it should not be free to swing, too close to the bar of steel, if this be strongly magnetized, otherwise the powerful magnetism of the bar may overpower that of the needle and reverse its polarity. In such a case the former north seeking end would become the south seeking end.

We have mentioned the needle and the bar as being made of steel because steel differs from iron in that it has the power to retain whatever magnetism it may be charged with for an indefinite time, while iron, especially if it be well annealed and soft, looses its magnetism the instant the magnetizing force ceases to act. A bar of iron will attract the needle as well as the steel but to a lesser extent; with the steel bar the attracting or repelling force will be due to the action of both magnets while with the iron bar it will be only the force of the needle that does the attracting.

Magnets consisting of hardened steel are known as permanent magnets and usually made up either in

Figure 3

horse-shoe shape or in the form of straight bars as shown in the following figures. It is impossible to make a magnet with one pole only. No matter into how many pieces we may divide a magnetized bar. each piece will possess a north and a south pole. This is illustrated in Figure 3 where the different poles are designated by the iron filings which cling to them. If these pieces be all joined again perfectly the intermediate poles will all disappear and there will be only the two poles, one at each end. It is, however, possible to arrange a bar magnet so that it shall have a number of poles throughout its length, even while it remains solid. This is illustrated in Figure 4, where

the two ends of the bar are magnetized in opposite direction so that two poles of same sign are formed in the center and oppose each other.

Consider now the horse-shoe magnet shown in Figure 5. If we take a magnet of this kind and sprinkle a lot of iron filings or small tacks about the ends they will be attracted and form around it in the manner shown. If the magnet is weak it will be necessary to assist the formation somewhat by gently placing the tacks where they will stick. If we now raise the magnet, a large part of the filings or tacks will follow and we can carefully put on a number more, but shall soon learn that there is a limit and that as we put on

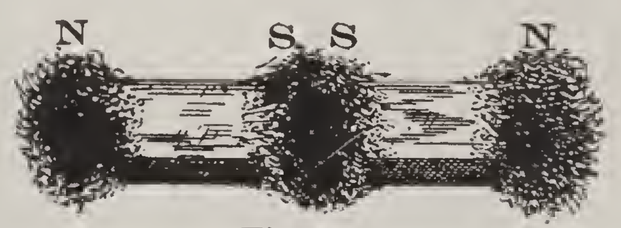


Figure 4

more tacks in one place some of the others will fall off. If we now take the armature A and place it across the pole of the magnet, say at O, by far the greater part of the tacks will fall off. The reason for this is that the magnetic flow or flux, as it is usually termed, follows along the lines of least resistance like any other flow. The armature offering a path of much lower resistance than the partially disconnected tacks simply shunts the flow around them and they cease to be attracted.

The magnetism is conceived to consist of a flow of lines of force as indicated in Figure 6. These lines are supposed to leave the magnet at the north pole N

and passing through the intervening space, to return to the south pole S of the same magnet. If we take a compass and beginning, say at the right hand end, move the needle along the path of the lines of force

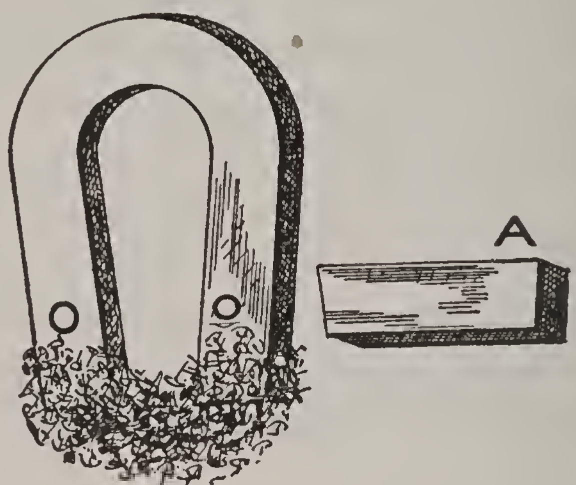


Figure 5

we shall see it align itself to them and as it is brought to the other end of the bar the other end of the needle will meet it. The flow of these lines of force is greatly facilitated by iron or steel but there is no medium

Figure 6

which can be interposed that will prevent the flow entirely; in other words, there is no insulation for magnetism. It is, however, possible to shield bodies from it by introducing an easier path for it as we have seen in the experiment with the tacks.

Permanent magnets are generally made by "touching," that is, a magnet is wiped across the end of the bar which is to be magnetized as shown in Figure 7. If the inducing magnet is strong it is not even necessary to bring it in contact with the bar to be magnetized. One must proceed in a systematic manner, however, that is, always touch the same end of the bar to be magnetized with the same end of the magnetizing bar and move it over the bar in the same direction. If this is not done one "touch" will neutralize the other and the result will be either no magnetism at all or at best but a very little of it.

Figure 7

Permanent magnets are often made up of a number of bars of equal length and shape fastened together and are then known as compound magnets. Permanent magnets can be demagnetized by heating to a red heat.

ELECTRO-MAGNETS

Electro-magnets differ from permanent magnets; first, in being made of soft iron instead of steel; second, the magnetizing force is not another magnet, but a current of electricity; third, the magnetism lasts only while the current is circulating in the wire wound

around the core; fourth, the strength of magnetism is variable and within certain limits in proportion to the current flowing; fifth, the polarity, or the direction of the lines of force changes with the direction of the current and can therefore be instantly reversed.

We may now consider the generation of magnetism by means of the electric current.

If we assume the black circle (Figure 8) to be an electrical conductor in which the current is flowing in the positive direction (i. e., away from us) that conductor will be surrounded by lines of force circling about it in the direction of the arrows shown. The number of lines of force will be directly in proportion

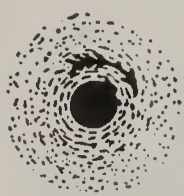


Figure 8

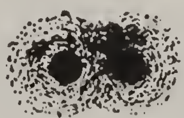


Figure 9

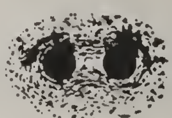


Figure 10

to the current strength (number of amperes) in the circuit. If we reverse the direction of the current the lines of force will circulate in the opposite direction. If we lay two wires, carrying current in the opposite direction, side by side as shown in Figure 9 the lines of force will repel each other and tend to separate the wires; if, however, these wires be carrying current in the same direction the lines of force will act in harmony and tend to draw the wires together as in Figure 10. These lines of force are, of course, only conceptions, but they are very natural ones. If wires such as those shown be thrust through a piece of paper or cardboard at right angles to it and if iron filings be

sprinkled on the paper and near the wires, these filings will have a tendency to arrange themselves in circles around the wires as outlined in the figures. In order to properly get such an ouline it will be necessary to gently jar the paper several times thus temporarily annulling the friction which tends to hold them in their place, so that they may more readily align themselves to the lines of force surrounding the wire.

If we now wrap a wire carrying a current of electricity around a bar of iron as shown in Figure 11 these lines of force will pass through the iron as depicted and we shall have a similar circulation of lines of force in this case as was observed in a magnetized

Figure 11

bar of steel. Magnetism is also produced by a coil of wire wound in this way that contains no iron but the magnetic flux will be much less. This is due to the fact that the iron offers a much lower resistance to the flow of lines of force than does air and hence their number is greatly increased. The law that governs magnetic flux is exactly similar to Ohm's law which governs current flow It is:

$$\text{Magnetic flux} = \frac{\text{Magneto-motive force}}{\text{Magnetic resistance}}$$

The magneto-motive-force is produced by the current circulating in the coil of wire and so far as mag-

netism is concerned it matters not at all whether the 100 amperes circulate once around the bar or certain air space or whether one ampere circulates 100 times. The magnetizing force is always proportional to the product of the number of turns of wire and the current flowing in the wire. This product is generally known as the "ampere turns."

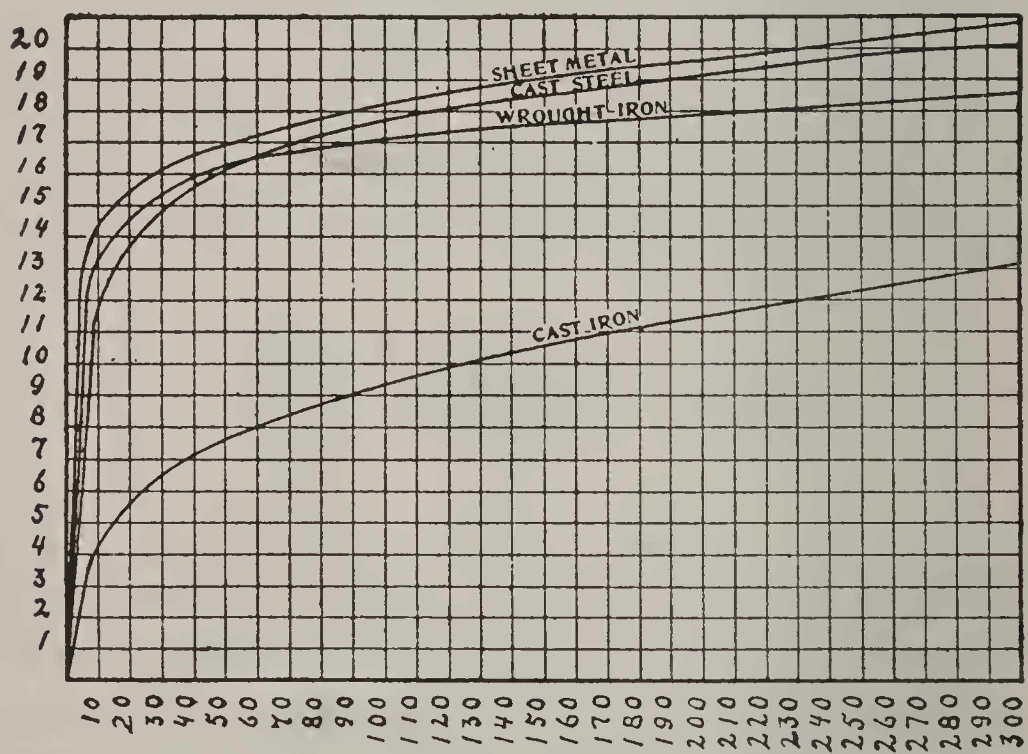


Figure 12

The magnetic resistance varies with the material used inside of the coil, or helix, as it is often termed. It is greatest with air (with exception of a few substances that need not be considered in practical work) and least with well annealed wrought iron. The magnetic resistance also decreases as the cross-section of the iron increases and, conversely, increases as the cross-section of the iron decreases, i. e., the core be-

comes smaller. The above is rigidly true only for air and approximately only within certain limits for iron. The conductivity of iron for lines of force has a limit and if we attempt to force too many lines of force through a given core a point will soon be reached where the iron assists the magnetization only to a very small extent and any further increase in the strength of that magnet will be little more than in the ratio that is possible for air. This is illustrated by Figure 12 which shows graphically, by means of the curves the relative magnetism produced in different kinds of iron and steel. The highest magnetization is possible with annealed sheet iron, the lowest curve shown is for cast iron. The numbers along the bottom line indicate the relative ampere-turns or magnetizing force and those along the vertical line the resulting magnetic flux or magnetism.

We have seen by Figure 11 how the lines of force produced by currents of electricity produce magnetism, either in the surrounding air or in a bar of iron. If we now coil another wire about the bar and send current through it in the opposite direction, or reverse a part of the winding in any coil so that current will circulate in the opposite direction we shall neutralize the influence of the first coil; that is, the lines of force produced by the two windings will oppose each other and there will be no magnetism if they are exactly equal to each other. If they are not equal then the resulting magnetism will be proportional to the difference in strength of the two opposing coils. It must not be understood that the number of turns of wire, size of wire, and current in the wire must be the

same, but that the "ampere turns" in the two coils must be equal. To find the difference we must subtract the ampere turns in the weaker coil from those in the stronger. It is not possible to quite neutralize the action of one coil by the action of the other but we can come very close to it and the remaining magnetism can be detected by the most delicate instruments only. Such a winding is known as "differential" and is made use of in many dynamos, motors, arc lamps, measuring instruments, etc.

We may now briefly consider the forms of magnets suitable for different purposes. The attraction of an

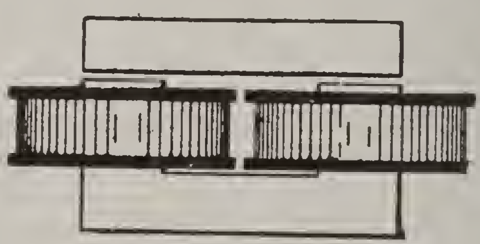


Figure 13

electromagnet for its armature varies as the square of the number of lines of force passing through both. If then we desire to obtain the greatest traction, we must see that we obtain the greatest number of lines of force that a given current can produce. For this purpose it is necessary to arrange the magnetic circuit so that it shall have the least possible resistance. This we obtain when we make the cross-section of the core large enough so that the magnetization need never be pushed beyond the nearly straight rise of the curves shown in Figure 12. The iron core should also be made as short as possible. We must, however, have space to place a certain number of turns of wire

around the core and it must be long enough to allow this. It need not be a bit longer. We must not, however, imagine that very much can be gained by crowding the windings together as shown in Figure 13, for in such a case the outer layers of wire become very long and introduce unnecessary resistance into the electrical circuit and also, this construction makes necessary an unusual length of the yoke. As a general rule it will be found advisable to make the thickness of the coil about equal to the thickness of the core; to make the yoke just long enough so that the coils

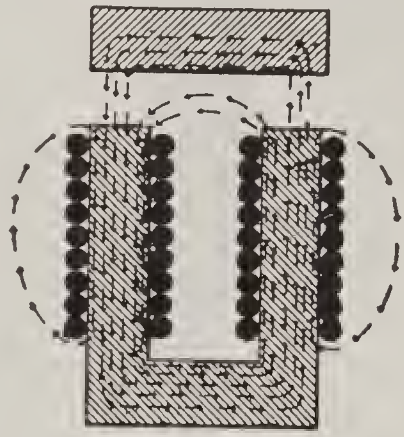


Figure 14

will not interfere with each other when they are being placed in position and to make the core long enough to accommodate the necessary wire.

In Figure 14 we have shown a cross-section through an electromagnet showing the windings surrounding the iron and a general scheme of the lines of force existing in such a magnetic circuit. The armature is shown out of contact with the magnet and there is also indicated a considerable leakage of lines of force. If the armature is brought down in contact with the core it will have a double effect upon the

lines of force; first, these lines will be increased in number because the resistance of the magnetic circuit has been lowered; second, because the leakage also is very much reduced. Reasoning from these facts we can readily see that the best proportions for the limbs of a magnet depend somewhat upon the use it is to be put to; whether the armature is to work close to the core, i. e., if the range of action is to be small the tendency to leakage will be small and we can let the poles of the magnet come reasonably close to-

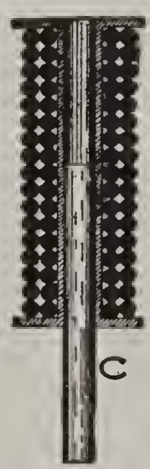


Figure 15

gether and make the magnet very short, but if the range of action is to be long we must separate the poles more and make the cores longer so as to lessen the tendency to leakage.

Different arrangements of the magnetic circuit are also necessary to provide for different speeds of action. The solenoid, Figure 15, has a very long range of action, it tends to pull the core C up into the coil but this action is, on the whole, very slow and not very sensitive to small currents.

Figure 16 shows a type of magnet that is very sensitive to small currents. The main yoke is a compound permanent magnet consisting of a number of pieces of magnetized steel fastened together. On the ends of these permanent magnets are fastened soft iron extensions and on these the magnetizing coils are wound. This form of magnet was invented by Prof. Hughes for use with a printing telegraph and means were provided to bring the armature tight against the poles where it would stick, held by the

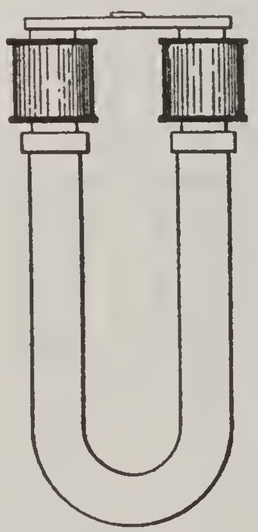


Figure 16

magnetism of the steel bars which also magnetized the soft iron ends. It was the function of the electric current circulating in the coils around the soft iron extension to oppose or neutralize this magnetism and thus release the armature. In this way the armature could be very quickly controlled and with very small currents.

For quick action the magnetic circuit should not be too good. The cores should be short, the winding extra thick upon them and the air gap between the

cores and the armature considerable. If the armature comes in contact with the cores the demagnetization is greatly retarded as this helps increase the hysteresis, of which we shall speak later.

A special form of magnet that is often used is diagrammatically shown in Figure 17. In this form of magnet the armature A is continually under the influence of the permanent magnet M. While current is passing through the coils in one direction one of the cores will attract the armature and the other will repel it. If the current in the coils is now reversed

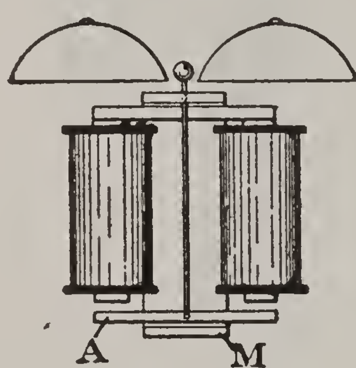


Figure 17

the magnetism will also be reversed and the armature thrown the other way. The end that before was attracted will now be repelled and the one that before was repelled will now be attracted. Under the influence of an alternating current the armature will move in time with the current and cause the bell to ring as long as the current flows. This form of magnet is also very sensitive and such a bell and all apparatus of this kind is known as "polarized."

The cores for alternating current magnets require to be laminated and thoroughly annealed. A laminated core is made up of a number of thin plates as

in Figure 18. The core is subdivided in this way as otherwise currents would be induced in the iron and these currents would heat the iron and cause considerable waste of energy. The oxidization on the plates introduces sufficient resistance to prevent the circulation of such currents.

There is another source of heating of alternating current magnets and this is known as "hysteresis."

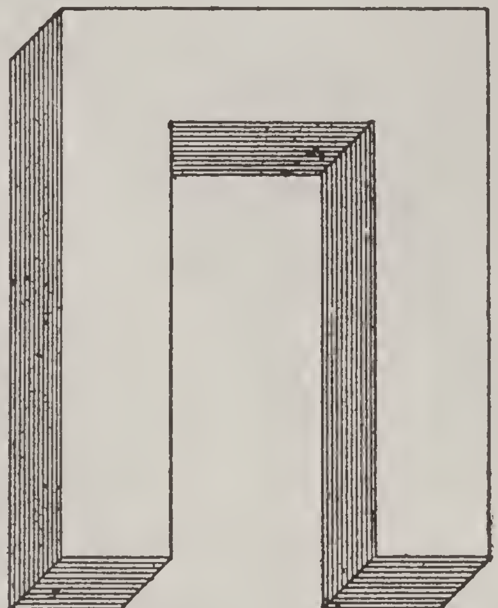


Figure 18

Every piece of iron has a tendency to retain some of its magnetism and this magnetism must, when the direction of current is changed, be dispelled. This effect is small with very good annealed iron but quite great with inferior iron or steel.

There is also assumed to exist a sort of friction between the molecules of iron of which every bar consists and that, with changes in magnetization these molecules are forced to align themselves in a different manner; thus if these changes are rapid and continu-

ous the friction of the molecules will also cause the iron to heat.

Figure 19 shows the waste of energy due to residual magnetism of different kinds of iron and steel.

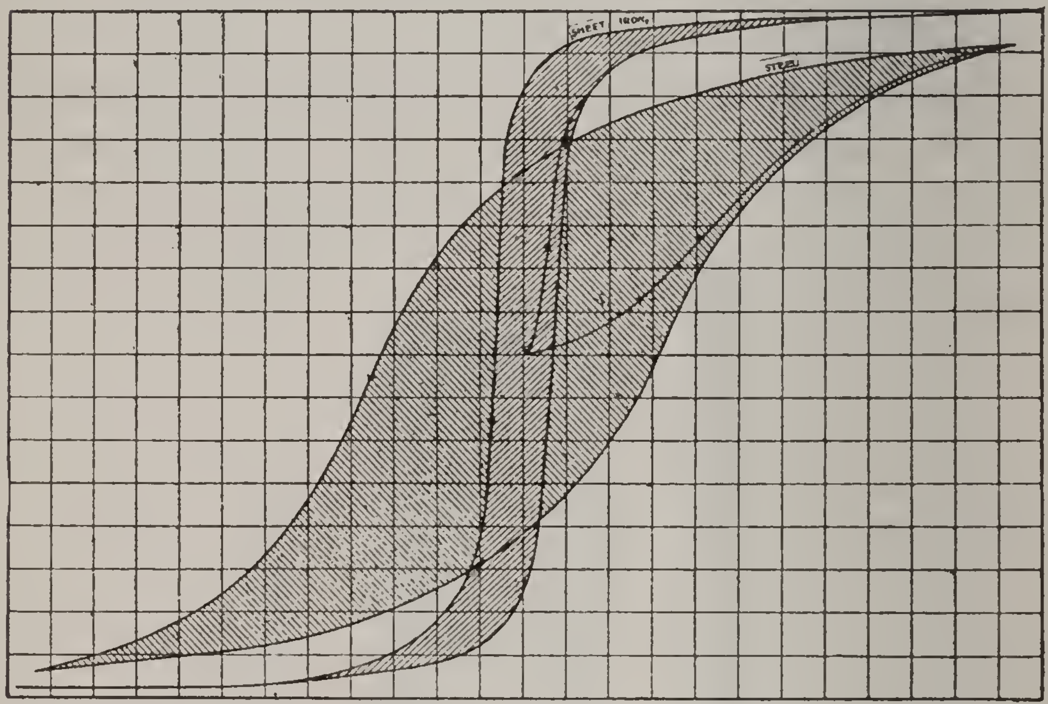


Figure 19

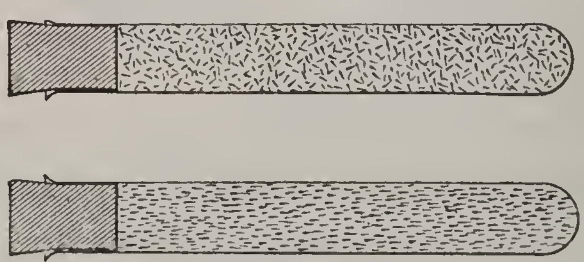


Figure 20

The shaded portion between the two sets of curves showing the relative amount of magnetizing energy wasted.

Figure 20 illustrates the molecular friction in an iron bar. With each reversal of current the molecules are supposed to reverse their positions.

WINDING OF ELECTROMAGNETS

We have seen that currents of electricity circulating in the wires wound around an iron core or bar produce magnetism and it behooves us now to learn the most advantageous way of applying such currents so as to obtain the greatest amount of magnetism from a given current. We know from Ohm's law that the current increases as the length of the wire in the circuit decreases. If then, considering a fixed electromotive force or E.M.F., we wind more coils around a given core, the current becomes steadily less as the number of turns increases. At the same time, however, the effect of what current there is increases because it circulates around the core oftener. If we assume the resistance of the wire around the core to be the only one influencing the current we shall obtain the following results. Suppose we have ten turns of wire, a resistance of one ohm and a pressure of ten volts, this will give us a current of ten amperes and consequently a magnetizing force of 100 ampere turns. Now double the number of turns, the resistance will be double and consequently the current only 5 amperes, but twenty times 5 again equals 100. So long as we use the same size of wire it will matter not a bit how many turns of wire we take, we shall still be able to get the same number of ampere turns from the same battery unless, however, the length of the wire necessary to make a turn increases very much as it will if a large number of layers are wound over each other. As the current decreases with more turns, while the E.M.F. remains constant throughout, it is

evident that we are getting our magnetism with less and less expenditure of energy as we put on more coils. How much energy it is advisable to consume in producing a certain flow of magnetism depends on circumstances. If power is cheap we can use a few turns of wire and a large amount of current, if it is dear we shall find it to our advantage to provide more windings and thus save energy.

The determining factor of the winding is, however, not alone the amount of energy we are willing to expend in the coils, but the temperature we are allowed to maintain. The magnetism created in any coil increases directly as the current but the heat generated increases as the square of the current. If in any coil we double the current we double the magnetism and at the same time increase the heating four-fold. The heating of the wires must therefore never be lost sight of.

Let us examine now how a change in the size of wire affects the economy of winding. If we take a coil containing say 100 turns of wire and place in the same space a wire of half the diameter of that of the first coil (neglecting differences that may be caused by variations in the relative thickness of the insulation) we shall obtain four times as many turns and the wire will have but one fourth of the cross-section of the former. Its total resistance will therefore be sixteen times as great as that of the old coil and from the same voltage it will receive but one sixteenth of the current; there will be, however, four times as many turns and the magnetizing force will therefore be one fourth that of the old coil. As the current is here

but one sixteenth of the former the energy expended per ampere turn will be but one fourth of the former. In this case again we receive from the energy expended per watt, a much greater amount of magnetism, but in order to get the same total amount we must increase the E.M.F. in proportion to the increased resistance divided by the increased number of turns, in this case sixteen divided by four.

We cannot always assume, however, that the coils of the magnet are the only resistance in the circuit. This would apply very well to the field coils of dynamos or the regulating coils of arc lamps, but not at all to telegraphy for instance. Here the magnets are long distances apart and far from the source of current and economy demands the use of small wires and these have high resistances. In such cases only a part of the energy is expended in the magnet coils. To illustrate the most advantageous winding of magnet coils for these conditions, let us assume the following case. Suppose we have an E.M.F. of 100 volts, a line resistance of sixteen ohms and a magnet which is wound with 100 turns of wire which just fill out the space allotted to the coils and which have a resistance of one ohm. This gives us a total resistance of 17 ohms and with 100 volts we therefore obtain very nearly 6 amperes making, 6 times 100 or 600 ampere turns. The energy consumed in this case will be about 600 watts. If we now try a wire of half the diameter of the former we shall in the same space have 4 times as many turns and each turn having only ¼th the cross-section will have 4 times the resistance, so that the total resistance of the coil will be 16 ohms and the

total of line and magnet 32. Our current will now be about 3.2 and give us 1280 ampere turns. The energy (in watts) consumed is now 320. For a third trial let us again take a wire of half the diameter of the former. The number of turns will now be 1600 and the resistance of the coil 256 ohms, giving us a total resistance of 272 and a current of about .4 amperes and a total of 640 ampere turns. The energy consumed in this case will be only 40 watts. Similar results will be obtained with all variations in diameter of wire and an inspection of these results will illustrate to us the rule, by which most designers of magnets for such work are guided, which is: make the resistance of the magnet coils in the circuit equal to the resistance of the line. If there are many magnets their combined resistance is made equal to that of the line. It must be understood of course that only copper wire of the highest conductivity should be used.

CHAPTER IV

PRINCIPLES OF DYNAMO-ELECTRIC MACHINES

The dynamo consists of two main parts, one of which is a huge electro-magnet, in the simpler forms approximating closely in shape to the horse-shoe magnets with which we are familiar. This magnet in the

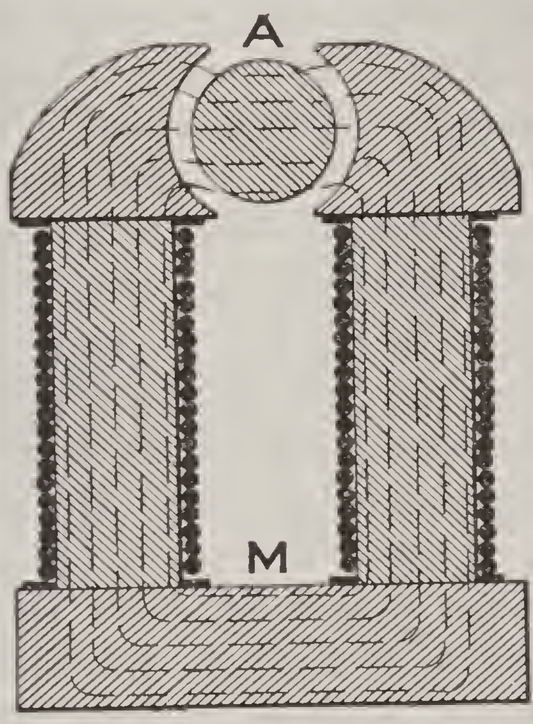


Figure 21

dynamo is known as the "field magnet" and is often spoken of merely as "the fields." In the simpler forms of generator these fields are usually stationary.

The other part of the dynamo is known as the armature. In all machines in which the fields are station-

ary the armature is made to revolve. In Figure 21 the fields of the dynamo are designated by the letter M and the armature by the letter A. Upon the iron core of the fields are always wound a number of turns of wire as upon any electro-magnet, and in this wire currents of electricity circulate, producing lines of force, just as in the different types of electro-magnets we have discussed in the previous chapter.

In the dynamo the electro-motive-force is developed by "cutting" lines of force. Lines of force are said to be "cut" when a conductor of electricity is moved in a magnetic field in a direction at right angles to the lines as indicated in Figure 22. Such a field is shown in Figure 22 between S and N and if the bar be moved through this field at right angles to the lines of force an E.M.F. proportional to the number of lines of force cut per second will be generated. No current will be generated in the bar as shown as it does not form an electrical circuit; but the fact that an E.M.F. exists could be readily shown by connecting a voltmeter across the ends of the bar. The direction of the flow of current generated depends upon the direction in which the lines of force are cut. By reversing the direction of motion of the bar, or by reversing the direction of the lines of force, i. e., reversing the current which produces them, the direction of the flow of current in the bar will be reversed.

The direction of the flow of current induced in any moving conductor may be determined by the following method: Place the thumb and first two fingers of the right hand in such a position that each forms a right angle with the others as shown in Figure 23. If the

thumb points in the direction of motion of the moving wire and the first finger in the direction of the lines of force, or from the north to the south pole of the magnet, the third finger will point in the direction of the flow of the induced current.

If the bar in Figure 22 is moved slowly the E.M.F. generated will be but small. If the number of lines of force remains constant, the E.M.F. will be directly proportional to the speed with which the bar is moved. If the speed of the bar remains constant the E.M.F.

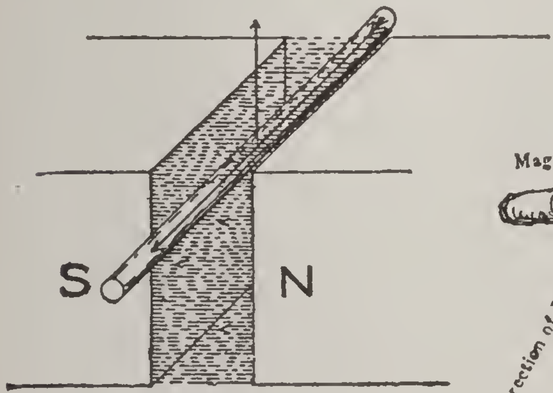


Figure 22

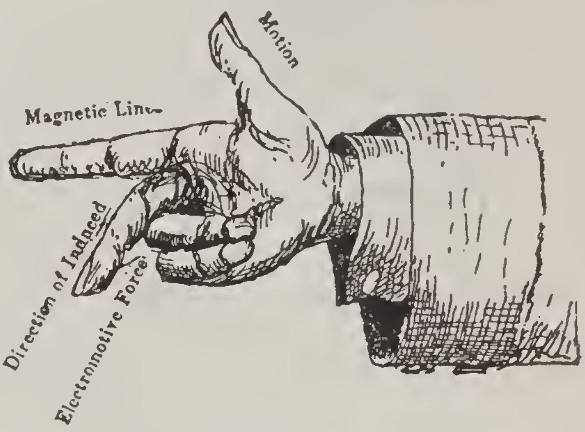


Figure 23

will vary directly as the lines of force vary. We can therefore raise or lower the E.M.F. of any dynamo by varying either the speed of the moving conductors or the intensity of the magnetization of the fields or by both.

An E.M.F. of one volt is obtained for every 100,000,000 lines of force cut per second. If therefore the gap in the iron of the fields has a cross-section of 100 square inches, and the magnetization is equal to 20,000 lines per inch, the bar would have to cut

through this field 50 times per second to generate an E.M.F. of one volt.

The generation of E.M.F. in this way is known as electro-magnetic induction.

Figure 24 represents a coil of wire the ends of which are connected to the two collector rings 1 and 2. Brushes bearing upon these collector rings connect the coil to the external circuit C. If now this coil of wire were revolved around an axis indicated by the dotted line through the center of it and in the

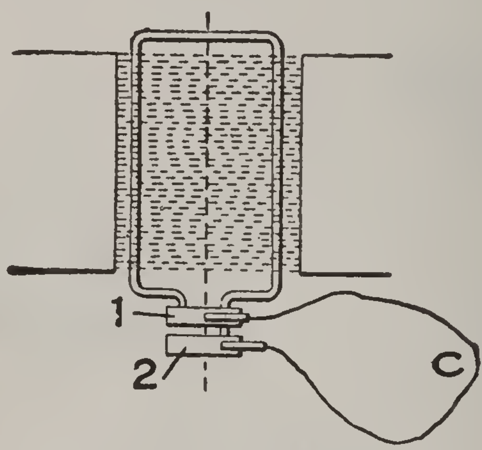


Figure 24

magnetic field, it would generate a current which would manifest itself in the outer wires C, either by heating them or by its effect upon instruments we may place in the circuit. We can get a clearer idea of the nature of this current and the laws governing it by reference to Figure 25 which shows an end view of the same coil of wire.

Let the points 1 1^1 represent opposite sides of the coil and let them revolve at a uniform rate of speed; they will then successively move to the points 2 2^1; 3 3^1; 4 4^1 until 1^1 is at the point now occupied by

1. The wires will in this time have made one half revolution. We have seen that the E.M.F. generated is proportional to the rate of cutting lines of force. We can see by an inspection of Figure 25 that the rate of cutting lines of force is not uniform, for at 1, for an instant the wire is moving practically parallel

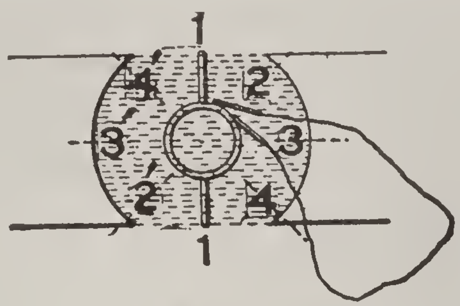


Figure 25

to them and is not cutting any. Also during ⅛ of one revolution from 1 to 2 it is not cutting nearly as many lines as during the time it travels from 2 to 3. In fact while the wires are at the exact points 1 1^1, no E.M.F. is generated, but as they pass this point it begins gradually to rise until 1 is at 3 when it begins

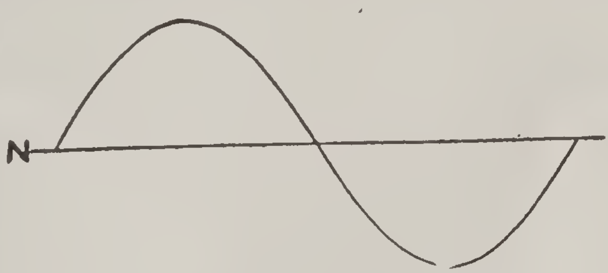


Figure 26

gradually to fall until 1 is at 1^1 when it is again at zero. When 1 has passed the point now occupied by 1^1 the E.M.F. again begins to rise but in the opposite direction, for the lines of force are now being cut in the opposite direction. The rise and fall of E.M.F. or current in an armature coil operating in this man-

ner can be illustrated by mean of "curves" as shown in Figure 26. Everything above the neutral line N being taken as representing E.M.F. in one direction and everything below as in the opposite direction. These curves show us also that the currents actually generated in a dynamo-electric-machine are alternating in direction and variable in strength. Alternating currents are not, however, always desirable and it becomes necessary to rectify them so as to obtain continuous or direct currents. For this purpose a commutator is provided.

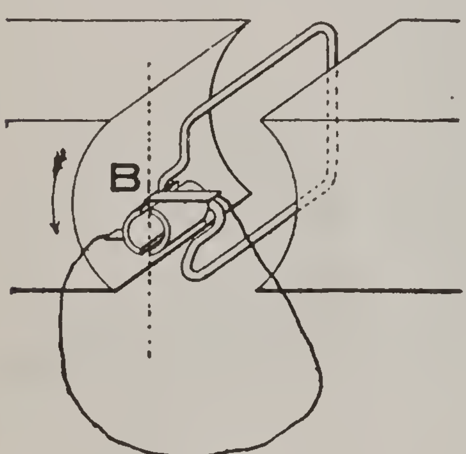


Figure 27

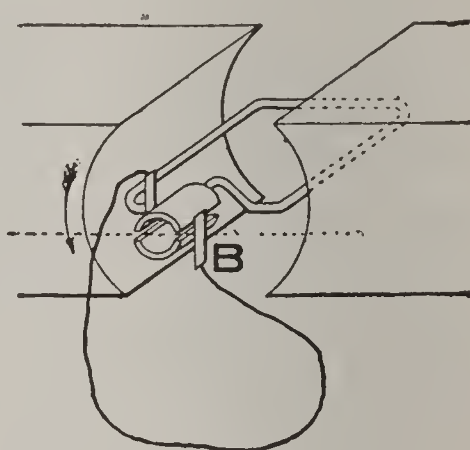


Figure 28

The nature and general construction of the commutator can be seen from Figure 27. It consists in these simple cases of two sections of copper connected to the terminals of the coils arranged as an armature. If the coil equipped with such a commutator is now revolved, it will be seen that just at the time when the open section of the commutator is in line with the dotted line in either one of the figures, the brushes B, which bear upon the commutator and connect it with the exterior circuit are in a position to change

from one section to the other. If the brushes are properly set this will occur at the precise moment when the coil is at the point where it is generating no current as in Figure 27. This is the point at which the current in the armature (coil of wire between the pole pieces) changes in direction.

The current in the armature continues to alternate, i.e., change in direction, at every half revolution, but by means of the commutator the coils are disconnected from one side of the external circuit and connected to the other so that the current in the exterior circuit remains always in the same direction. The E.M.F. or current generated by an armature containing only

Figure 29

one or a few turns of wire like the one shown would still produce a pulsating current and this current would be represented by such curves as are shown in Figure 29. These currents are all in one direction but vary in strength from zero to the maximum of which the machine is capable.

It will be noticed that the brushes, during the moment they are changing from one commutator segment to the other, are in contact with both of them. It could of course be arranged to avoid this by making the brushes narrow and the space or insulated material between the two segments wide so that the brushes would leave one section before they came in contact with the other. This would, however, cause

an opening of the circuit every time the armature made a half revolution and would result in very unsatisfactory lighting and motor service besides causing very annoying and destructive sparking, as every break in an electric circuit is accompanied by an arc which rapidly eats away copper and insulating material. The brushes connecting together the two segments, it will be seen by inspection of Figure 27, cause the coil to be on short circuit during the time that the brush is in contact with both of them. If this happens while the coil is in a position where it is not generating any E.M.F. and consequently no current is flowing no harm will be done; but if this occurs at a time when the coil is in an active part of the field and generating, a very considerable current will be produced because the resistance of such a coil is usually very low. This current will heat the wire and cause considerable waste of energy,—energy that should appear in the external circuit, but now does no useful work. Aside from this waste of energy and troublesome heating of the armature, when the brush breaks contact with one of the segments, this current will be broken and manifest itself in the form of a spark which, recurring often, will quickly destroy the commutator.

Not only this, but the commutator, if the position of the brushes is very wrong, as in Figure 28, would fail of its purpose and not rectify the current at all. With a single coil and the brushes set as in Figure 28 the current would be graphically represented by curves such as shown in Figure 30, it would still be an alternating current changing in direction in an

irregular way. In practice armatures do not consist of a single coil and only in very exceptional cases would these considerations in the extreme form apply. The commercial armature has a greater number of turns of wire and for bipolar, or the simpler machines,

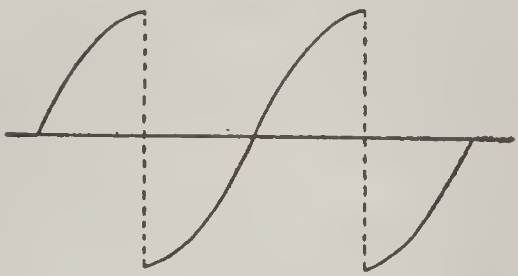


Figure 30

is made up either as shown in Figure 31 or diagrammatically in Figure 32 which is known as the gramme ring type of armature, or as shown in Figures 33 and 34 which is known as the "drum" armature.

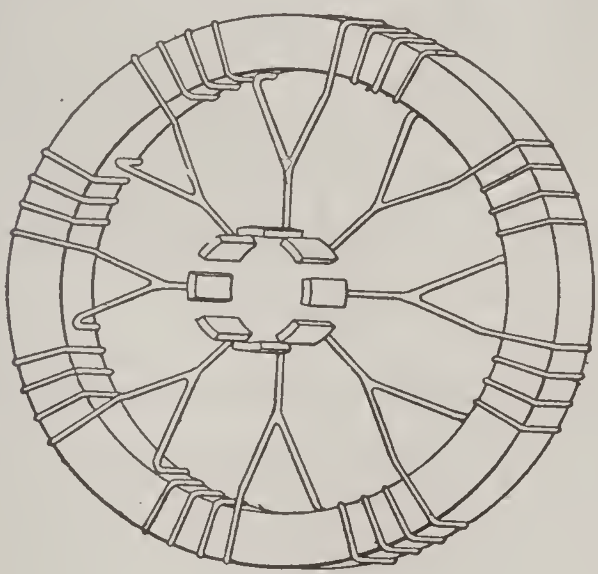


Figure 31

By reference to Figure 32 we can continue our study of the armature in a more commercial form. By noting the position of the brush B we can see that it is about to short circuit the coil connected to the two

segments to which it is nearest. This coil is, however, only a small part of the whole and a wrong placing of the brushes would not have the effect outlined before in regard to armatures having but one coil. No matter how the brushes may be set, they short circuit only one coil each and therefore only a small part of the current is ever broken or changed in direction at one time. As the resistance of such a coil is, however,

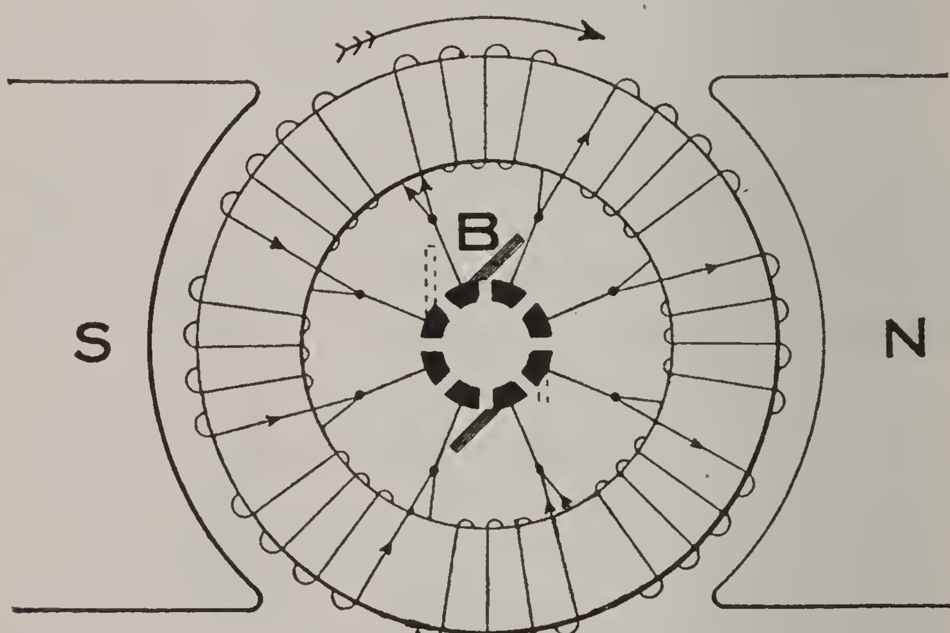


Figure 32

very low the current generated in it is, if it is in an active part of the field at the time, quite sufficient to cause trouble, which usually indicates itself by more or less severe sparking. If the coil is located in the neutral part of the field as that of Figure 32, for instance, there will be no sparking. The smaller each individual coil is made the easier it becomes to realize this condition and for this reason dynamo armatures are generally made up of a large number of coils, and

of course a corresponding large number of commutator segments.

The position of the brushes also has a great deal to do with the E.M.F. generated by the dynamo. To comprehend this let us again refer to Figure 32. The lines of force are passing through the fields and armature in a certain direction, from N to S. We know that the direction of the current depends upon the direction in which these lines are cut by the wires. As the armature is revolving always in the same direction those lines at S are cut in an opposite direction

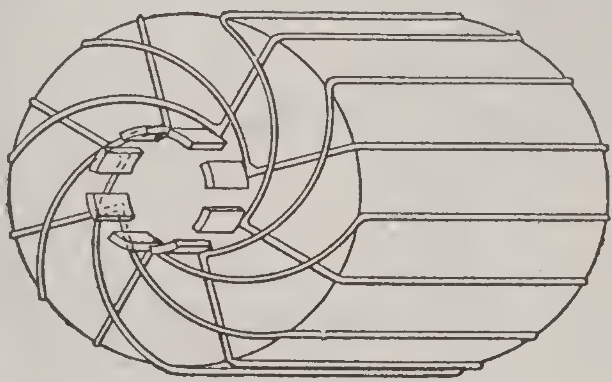


Figure 33

from those at N, consequently the currents generated in the two halves of the armature are flowing in a direction towards each other; this causes them to meet at the positive brush, flow out through the circuit and return to the negative brush, dividing again in the armature. In this way it can readily be seen that the two halves of the armature are in parallel. Now let us move the brush one section forward. Before, we had two coils in the neutral part of the field, generating no current, and three coils under the influence of each field doing active work. Now we have still two coils in the neutral field, idle, and the currents in each

direction are generated by two coils under the influence of each field and one under the influence of the the other; but this latter coil is not generating in harmony with the other two, it is actually opposing them as it is under the influence of the opposite field. This position of the brushes is therefore not only the cause of much sparking but also reduces the voltage of the dynamo. By shifting the brushes, forward or back,

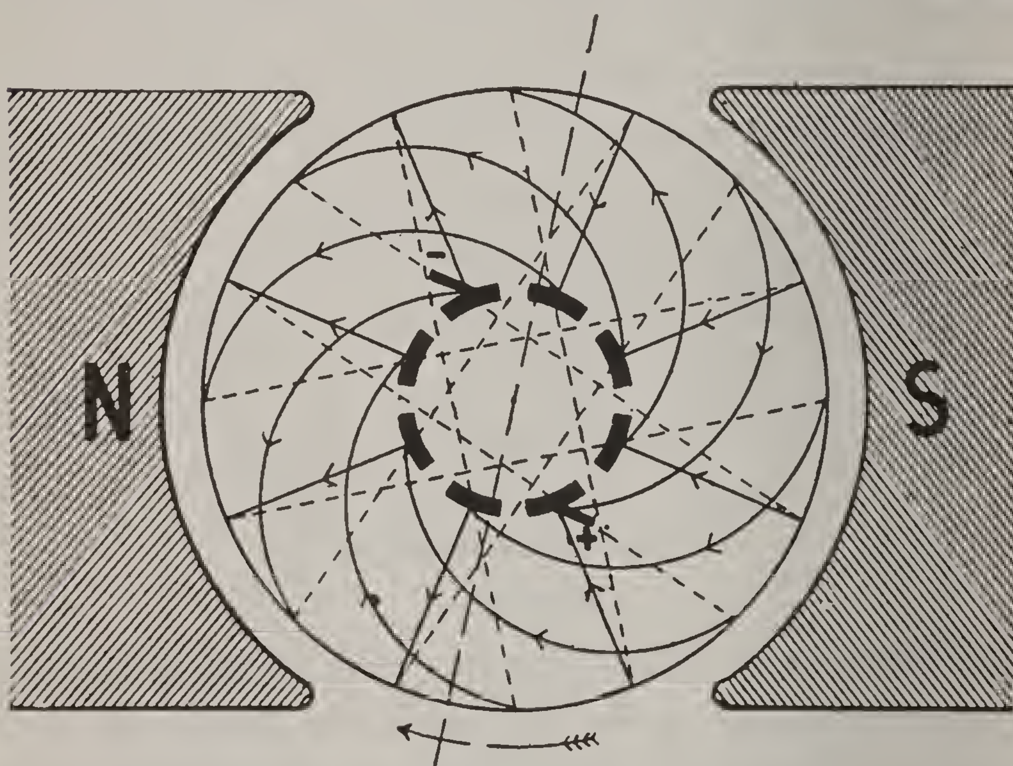


Figure 34

until they are at right angles to the neutral line the voltage can be reduced to zero. If the brushes are shifted still farther the voltage will again begin to rise but in the external circuit current will be in the opposite direction.

In present day practice the brushes are used to regulate the voltage of dynamos only in exceptional cases which will be considered in another chapter. The

necessary regulation is almost invariably brought about by means of a variable resistance or "rheostat." Such a rheostat is cut into the field circuit of a dynamo as shown in Figure 35 which shows a diagram of a simple shunt dynamo, A being the armature, F the field wires, R the rheostat and L the exterior or lead wires of the dynamo. When the machine is in operation current circulates around the fields and through the wires of R. The arm of R is a conductor

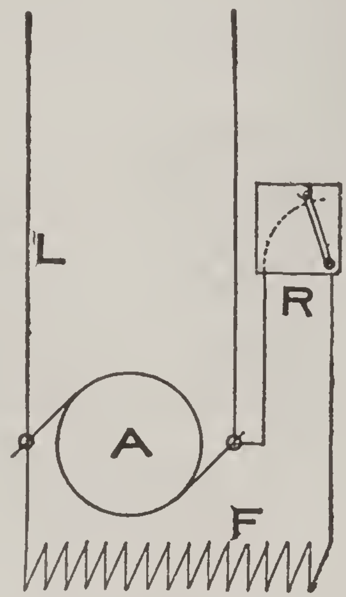


Figure 35

and is movable. In the position shown the current in the wires must traverse the greater part of the wires in R. If the arm of R, however, is moved to the left it gradually cuts out coil after coil until when it arrives at the last notch all of the resistance of R is out of the circuit. The resistance of the circuit is then at its lowest and consequently the current at its highest value and the field the strongest. By moving the arm in the opposite direction we cut more re-

sistance into the circuit and thus weaken the fields of the dynamo.

By moving the bar in the proper direction we can therefore increase or decrease the current strength in the fields and thus change the number of lines of force in the armature and these in turn (speed of armature remaining unchanged) will govern the E.M.F. of the generator.

The current flowing in the external circuit depends upon the E.M.F. and the resistance in the circuit. The current is all generated in the armature and of

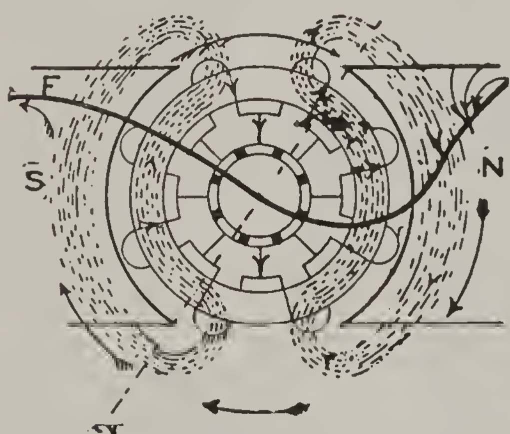


Figure 36

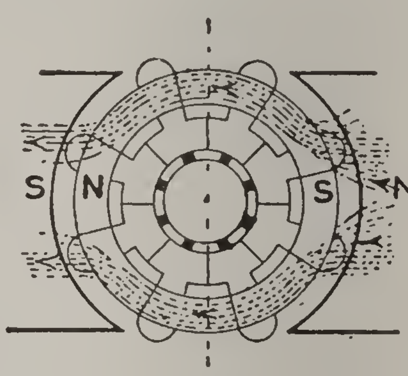


Figure 37

course all passes through it. And this current also makes a magnet out of the armature and the resulting magnetism opposes the magnetism of the fields to a certain extent as we shall see by reference to Figure 36. We can determine the direction of current in an armature by the following rule which has already been given but is repeated here for convenience of the student. Grasp the north pole of the dynamo with the right hand arranged as in Figure 23. Let the index finger point in the direction of the lines of force and the thumb in the direction of motion; the middle fin-

ger will then point in the direction the current is said to be flowing. With condition as shown in Figure 36 the current will be flowing around the armature as indicated by arrow points. Current flowing in this direction will produce lines of force in the armature as indicated by the other arrow points. It will be noted that these lines of force oppose those coming from the N pole to a certain extent. As lines of force can never intersect each other the result of this opposition is that the lines of force which pass through the armature and induce poles in it as shown in Figure 37 while no current is flowing in the armature, are deflected to a certain extent as shown in Figure 36.

Figure 36 shows the counter-magnetization of the armature which results in deflecting the lines of force from the fields somewhat in the direction of motion of the armature. In actual practice the lines of force from the fields reverse those of the armature but are deflected by them and the general trend of the resultant lines of force is indicated by the curved line F, Figure 36.

The neutral point or point at which the brushes must be set for least sparking is therefore no longer in the center between the two pole pieces as in Figure 37, but is shifted somewhat in the direction of motion of the armature as in Figure 36. If we reverse any one of the conditions the current will be reversed but the same relation between shifting of the neutral point and direction of motion will always hold. The countermagnetization of the armature increases as the current increases and therefore it becomes necessary to shift the brushes in the direction of motion as the load

increases and in the opposite direction as the load decreases.

It is evident that this shifting of the brushes which becomes necessary when the current flow in the dynamo changes, depends almost entirely upon the relative strength magnetically of the fields and armature. If the machine is so constructed that the magnetism of the armature is very strong, then, as the current increases the magnetism will increase and greatly shift the neutral line and make necessary considerable shifting of the brushes. But if the fields are very strong compared to the armature the latter will have but little effect and but a very little shifting of the brushes will be necessary.

In connection with dynamos two terms are often used erroneously as having the same meaning. These terms are electro-motive force or E.M.F. and difference of potential or P.D. for short. Strictly speaking, the term E.M.F. refers only to the greatest difference of potential the machine or battery can produce and this P.D. can exist only while an infinitesimally small current is flowing. Whenever any appreciable current is flowing there is always a loss of potential which is always equal to $I \times R$. To get the maximum voltage of a dynamo we must therefore arrange that no current except that through the voltmeter be flowing. In a poorly constructed armature the difference between E.M.F. and difference of potential is considerable.

Aside from the foregoing there are many other points about dynamos that require explanation but these can more readily be treated in connection with

the particular type of machine in which they are of greatest importance.

In general a good dynamo has a large number of commutator sections. (To avoid sparking.) A magnetically weak armature and strong fields. (To avoid shifting of brushes.) The fields are wound with many turns of fine wire. (To save energy. See chapter on magnetism.) A small air gap between fields and armature. (To prevent leakage and unnecessary magnetic resistance.) The ends of pole pieces not too close together. (To prevent leakage around armature.) Large wires on armature. (To prevent loss of voltage and heating.)

CHAPTER V

TYPES OF DYNAMOS

The oldest type of dynamo is shown diagrammatically in Figure 38. The use of this type is generally restricted to direct current arc lighting. It is known

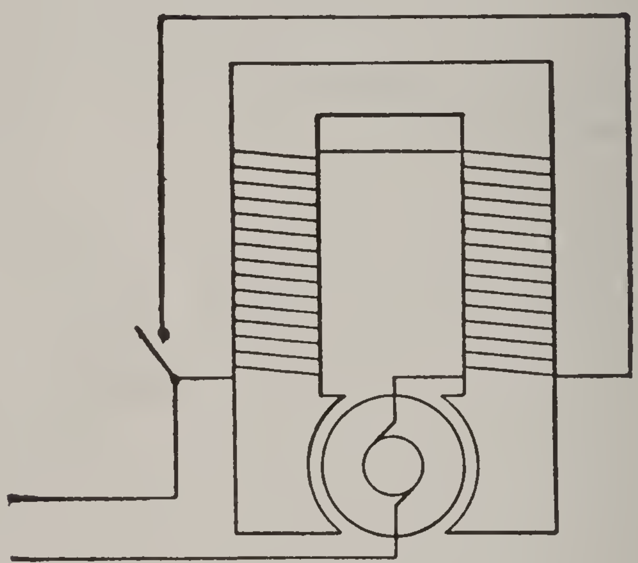


Figure 38

as the series dynamo, the same current passing in series, first through the armature, then through the fields. Such a machine cannot be used with a variable current because the strength of the fields would be constantly fluctuating. Whenever there would be an increase of current strength there would also be an increase in voltage and with a decrease in current strength there would be a drop in voltage. As the potential of series arc circuits is generally very high,

shunt wound dynamos would require a great length of very fine wire and consequently would be very expensive and also very likely to be damaged. This is one reason why series dynamos are in special favor in connection with series arc circuits.

The regulation of this type of dynamo always has as its object the raising of the E.M.F. as more lights are cut into the circuit and a corresponding lowering of it as lights are cut out of the circuit, so that the

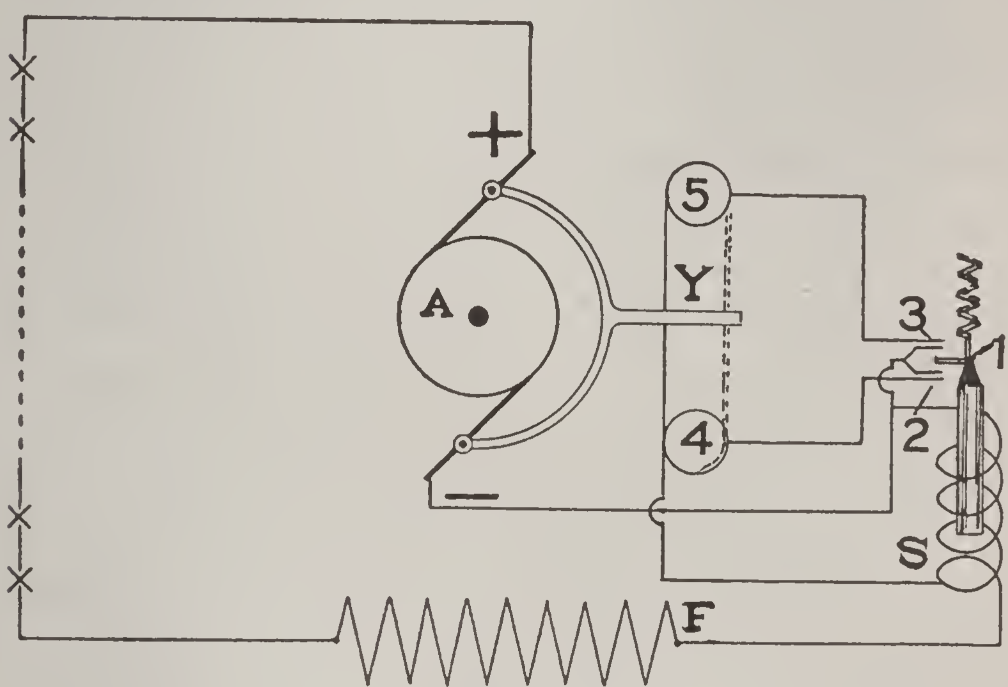


Figure 39

E.M.F. is always at its proper value in regard to the resistance of the circuit to cause the necessary current to flow. This regulation is generally brought about in one of the following ways: By shifting of the brushes, by commutation of the fields, or by a combination of these two methods.

The method employed of shifting the brushes automatically is diagrammatically illustrated in Figure

39. The total dynamo current passes from the positive pole of the armature A to the lamps, thence to field F, solenoid S and negative pole of dynamo. We know that the solenoid has power to control the position of the core within it. The stronger the current the farther will the core be pulled in in opposition to the supporting spring. This core is so arranged that with the normal current strength the extension 1 rests about midway between the points 2 and 3. If now there is a slight increase in current strength, as when a lamp is switched out, the core will be drawn downward and close an electric circuit at 2. This circuit is a shunt to the solenoid and requires but a small current. When it is closed current passes through the clutch 4 and this (by a mechanical contrivance not shown) causes the yoke Y to be drawn over so that the brushes are shifted in the direction which causes a lowering of the voltage and a decrease in current strength. As soon as the current goes back to its normal strength the circuit at 2 is again open and the brushes remain at rest until another change in current strength causes the solenoid to change its position. If the current becomes too weak the spring draws the solenoid up until the circuit at 3 is closed and the brushes shifted in the opposite direction by means of clutch 5.

The principle of varying the E.M.F. by field commutation is illustrated in Figure 40. The automatic control is not shown and instead hand control is used. By moving the lever L to the right or left more or less of the field winding can be cut into the circuit.

Instead of cutting out field coils, a resistance R (see

Figure 41) is sometimes arranged as a shunt around the field coils and as the arm is moved forward or back the resistance is increased or decreased, thus taking more or less current around the fields and weakening or strengthening them accordingly.

The highest E.M.F. of which the dynamo is capable is obtained when the brushes are near the neutral point. This position of the brushes can only obtain when the maximum number of lights are in the circuit. With a lesser number of lights the brushes must

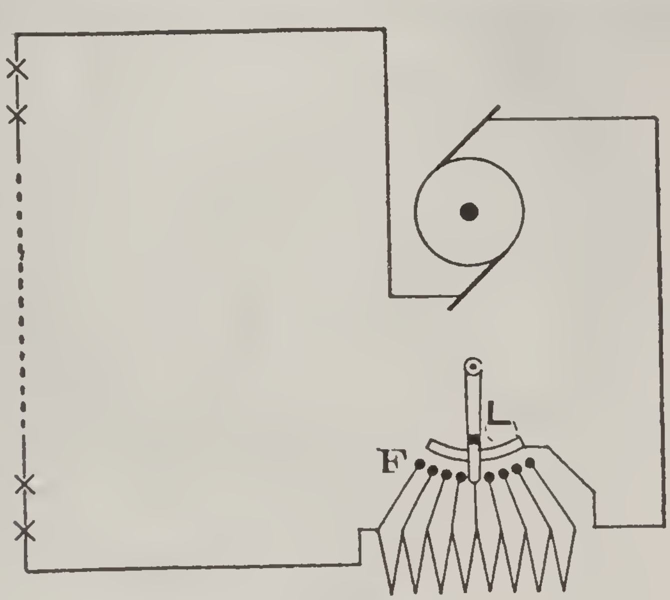


Figure 40

be shifted away from the neutral point sufficient to cause a certain number of the armature coils to generate in opposition to the rest and thus reduce the E.M.F. of the dynamo until the current has its predetermined value.

From what we have learned in chapter on Principles of Dynamos it is evident that all dynamos subject to such regulation must spark considerably at the brushes. There must also be considerable tendency

toward heating of armature wire with this kind of regulation as some of the coils are nearly always on short circuit. This applies also to a great extent to machines regulated by field commutation. Machines of this type are in consequence usually equipped with some special form of commutator calculated to withstand the destructive effects of the arcs formed. In the Thomson-Houston dynamo a blower is provided which blows out the arc.

For dynamos of this type the Gramme ring armature is preferable because from the nature of its wind-

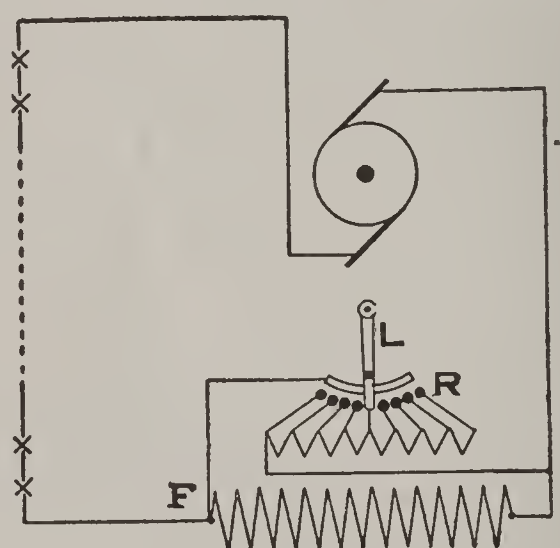


Figure 41

ing wires of opposite polarity do not cross each other as they do in drum armatures.

Two special types of dynamos very generally used for series arc lighting are the Brush and Thomson-Houston.

Figure 42 shows the coils and commutator sections of an 8 coil Brush arc dynamo. The diametrically opposite coils 1-1; 2-2, etc., are connected in series and each coil has its own exclusive commutator section.

By tracing out the circuit from the brush A, it will be seen that current enters at this brush, passes through coil 1-1 to brush A[1]; thence to field H, brush B, coils 2 and 4 in parallel, thence to brush B[1] and out at the positive pole of the dynamo.

With this armature one coil is always on open circuit and the adjustment must be such that this coil while open is in the dead part of the field. Each commutator segment embraces three eighths of a circle.

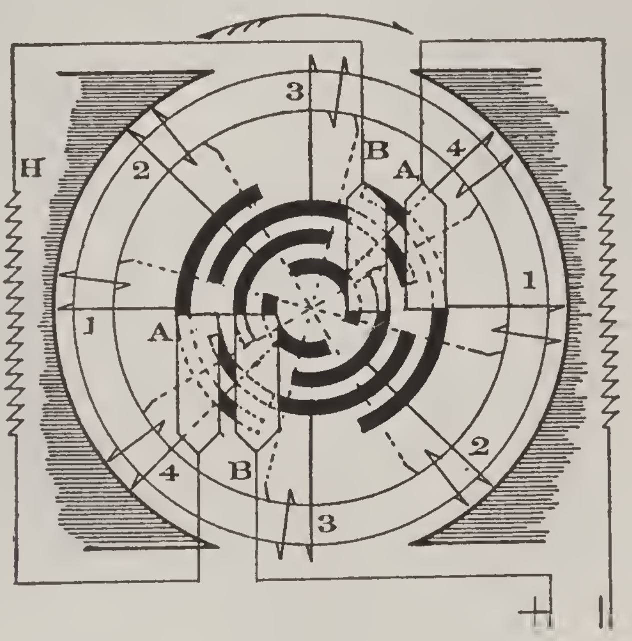


Figure 42

As the different coils are not in series with each other but at times in parallel the brushes must be so arranged that at no time can a coil that is not generating be left in circuit. Such a coil would simply form a short circuit to the line and much of the current that should flow through the line would flow through it. By following out in imagination a complete revolution of the armature one can see that the brushes always break contact with the coils as they pass

out of the influence of the fields. It is very important to see that the commutator is always set with regard to this.

The Thomson-Houston is another type of open circuit dynamo armature. The nature of its winding is shown in Figure 43. One end of each coil is connected to one of the 3 commutator sections and the other to a brass ring R common to all the coils.

A series dynamo if left without regulation will, with an increase of current, run its E.M.F. to the maximum of which it may be capable and probably burn out. The greater the current the greater will be the pressure, but after the fields have become fully saturated the increase in E.M.F. will be small. Figure 44 shows the characteristic curve of such dynamos. Such curves are obtained by plotting the E.M.F. and current existing at the same time on squared paper as shown and then combining the points so obtained in a curve. This may be to any convenient scale. The figure shows only the general outline of such curves

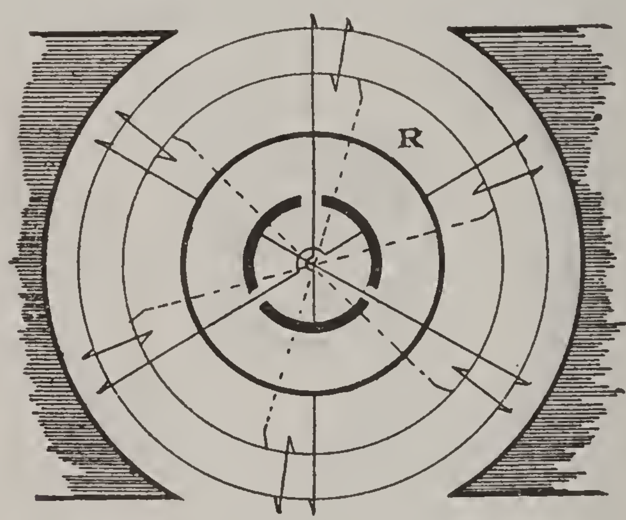


Figure 43

as they are of course different with different types and design.

For incandescent lighting, motor service, constant potential arc lighting and storage battery work the shunt dynamo is much used although of late years the

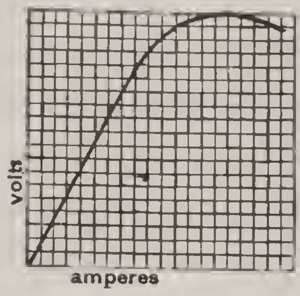


Figure 44

compound wound dynamo is crowding it out. Figure 45 is a diagram of the shunt dynamo. This dynamo is generally equipped with a drum armature. It is sel-

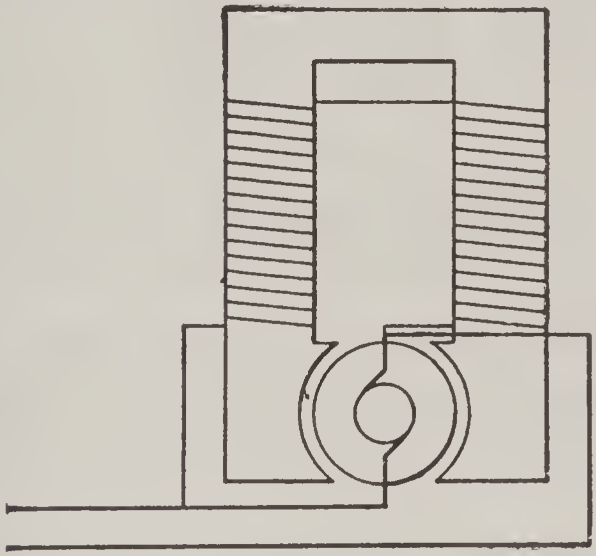


Figure 45

dom if ever equipped with an automatic regulator and instead hand regulation is used. The drop of potential at the brushes is equal to the current multiplied by the resistance of the armature. In a poorly con-

structed armature this is considerable so that such a machine needs constant watching. An appreciable drop in potential is of course accompanied by a weakened current through the fields which in turn allows a further falling off in potential.

The characteristic curve of a shunt dynamo is given in Figure 46. If the potential of such a dynamo falls off noticeably the fields begin to weaken and thus increase the falling off in proportion. A shunt dynamo if short circuited will for a very short time increase its current enormously and will then lose its pressure, the short circuit robbing the fields of all current. The

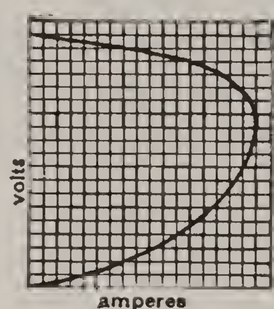


Figure 46

curve in Figure 46 shows the effect of an overload which is nearly or fully equivalent to a short circuit. After the maximum current has been reached the pressure falls off so much that the current also decreases and both current and E.M.F. finally return to 0.

As all armatures have some resistance it follows that the potential at the brushes of any shunt dynamo must fall as the current increases. To compensate for this a special winding through which the whole dynamo current flows is put upon the fields in addition to the shunt winding. As the drop in potential is

always exactly in proportion to the current flowing, it is evident that if this current be made to circulate the proper number of times around the fields it will increase their strength so that the E.M.F. of the dynamo will be raised just enough to make up for the loss due to its armature resistance and the E.M.F. remain very nearly constant. (See Figure 47.) If the current be made to circulate a greater number of times the E.M.F. of the armature will go higher as the current increases. It is therefore possible to

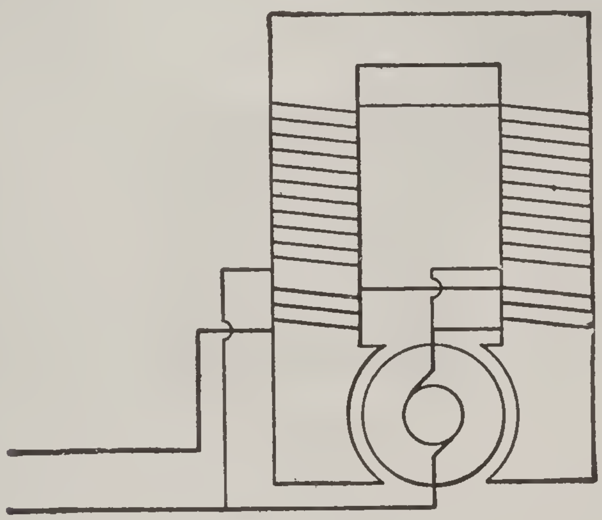


Figure 47

arrange such dynamos to keep the pressure constant even at points far away from the machine, but in such cases it will go undesirably high at the dynamo terminals.

The characteristic curve of a compound wound dynamo is a combination of the curves of a series and shunt machine and shown in Figure 48. If such a dynamo is short circuited the shunt fields will immediately lose their magnetism but the power of the series coils will be momentarily increased as there will

be for a very short time a great flow of current, due to the fact that an instant of time is necessary before the magnetism of the fields passes away. If the series fields are very strong compared to their own and the armature resistance they will energize the fields on their own account and the armature will burn out. If it is very weak relatively to those two factors, little harm will be done if the armature has withstood the momentary rush of current which could last only long enough for the shunt fields to die down.

So far we have looked upon all machines as having but two poles. Such machines are known as bi-polar.

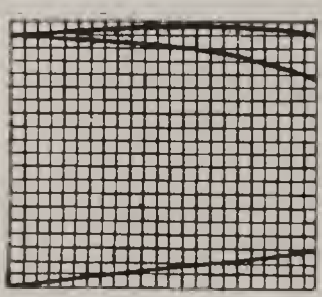


Figure 48

Most of the larger machines are, however, multipolar, i. e., equipped with more than two poles. The magnetic circuits and arrangement of pole pieces in a 4 pole machine are shown in Figure 49. With such machines there is usually a set of brushes for each set of poles. The neutral point will be about midway between two pole pieces. If the brushes are moved a quarter revolution forward or back the directions of current will be reversed. Armatures for such machines may be wound just as for bi-polar fields but a form of winding as indicated in Figure 50 is preferable.

Figure 50 is a diagrammatic view of the simplest form of multipolar armature winding. The wires are laid in slots on the outer circumference of the armature and are shown as though the armature were cut

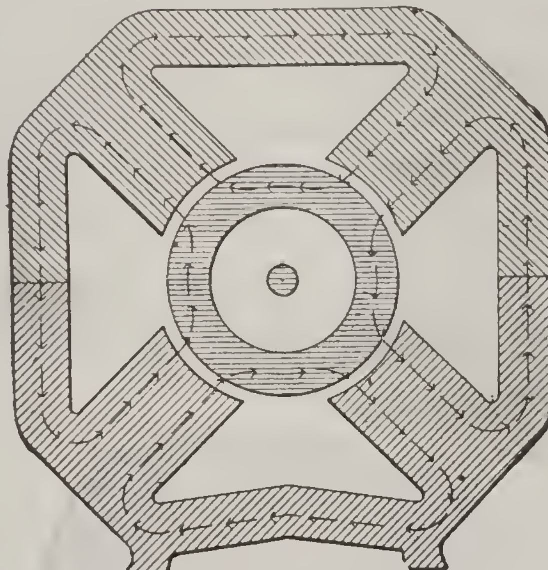


Figure 49

in two and the wires laid out flat. W, W represents the commutator sections and N, S, the poles as in Figure 49.

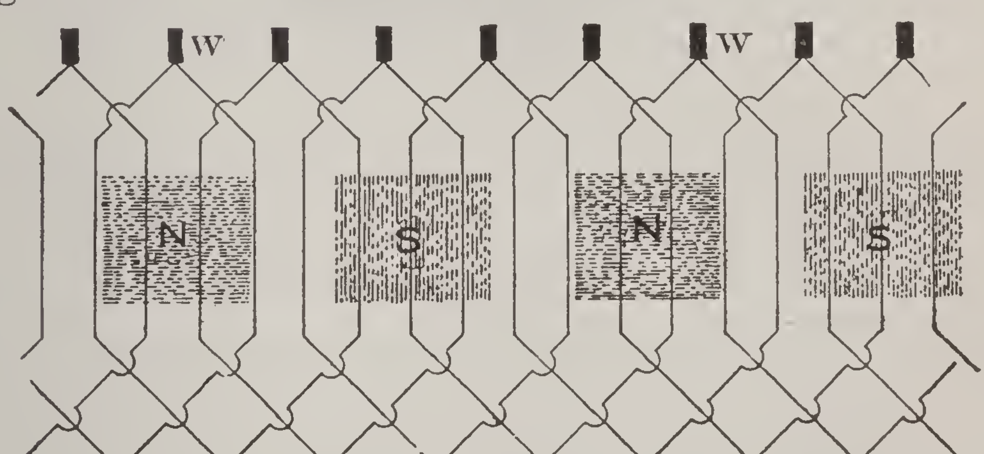


Figure 50

A view of a finished armature is given in Figure 51. Alternating currents to be available for lighting purposes must have quite a high frequency; 60 cycles

per second or 7200 alternations per minute being about the lowest frequency that can be used for arc or incandescent lighting without causing annoyances through flickerings in light. If such frequencies were to be produced by a bi-polar machine it would have to operate at a speed of 3600 revolutions per minute. As these machines also generally operate at very high pressure there would also be, with drum armatures, great danger from wires between which great difference of potential exists crossing each other. To obviate the above troubles alternators are usually made

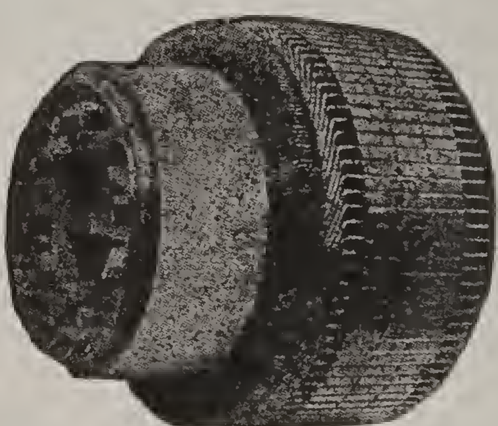


Figure 51

multipolar, both, fields as well as armature, consisting of a number of sections.

The alternating current dynamo may have its armature stationary and the fields revolving; it may have the fields stationary and the armature revolving or the fields and armature may both be stationary. In the latter case it is described as belonging to the inductor type.

An alternating current cannot be used as such to excite the field and consequently many dynamos are

separately excited by an outside dynamo. Some alternators, however, are provided with commutators which rectify the current and make it available.

Figure 52 shows the general layout of an alternating current dynamo with revolving fields and stationary armature. The dynamo is excited by direct current from a shunt dynamo, the current entering at D.C. and passing around the fields. The strength of

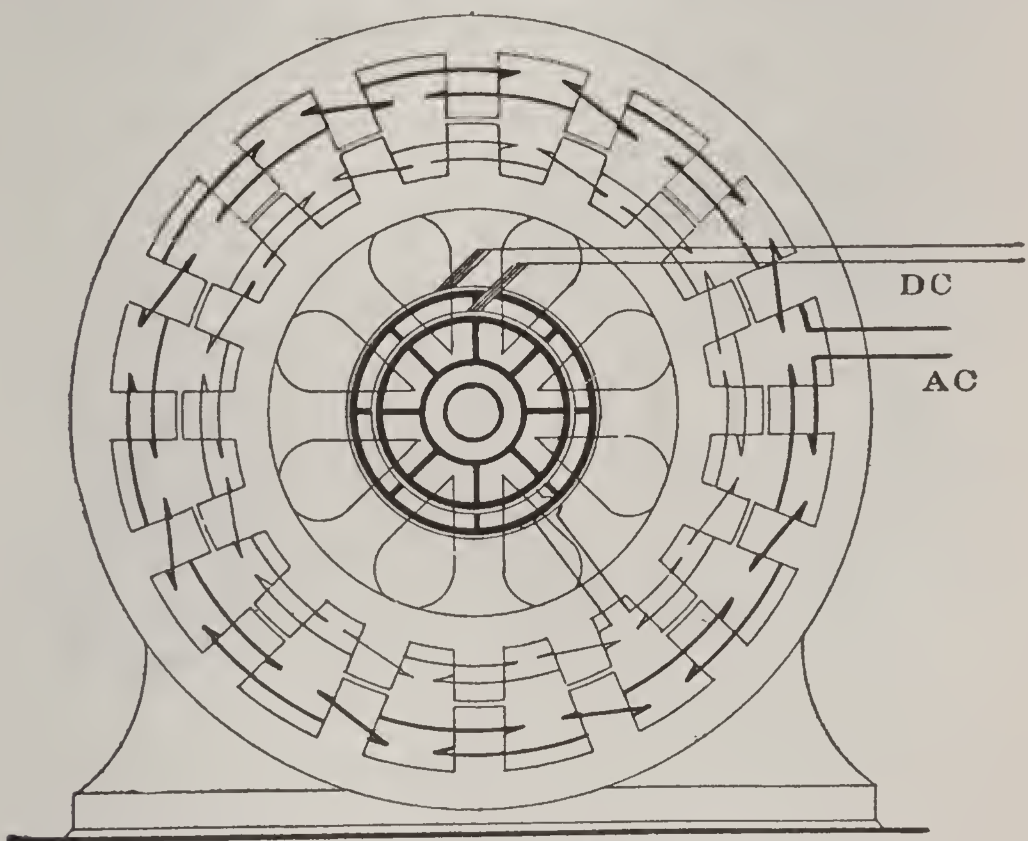


Figure 52

this current can be regulated and through it the E.M.F. of the dynamo.

Every time one of the armature poles passes from under one of the stationary poles to the next one there is a reversal in direction of the current.

If supplying a variable load the E.M.F. of the dynamo will be constantly fluctuating, the drop increas-

ing as the load increases and with this machine there is only hand regulation.

In order to avoid the necessity of constant attendance and hand regulation alternators are sometimes compound wound just as direct current machines. The field of such a machine consists of a steady current from the D.C. dynamo supplemented by a pulsating current from the generator itself.

In order that the generator current may be used it

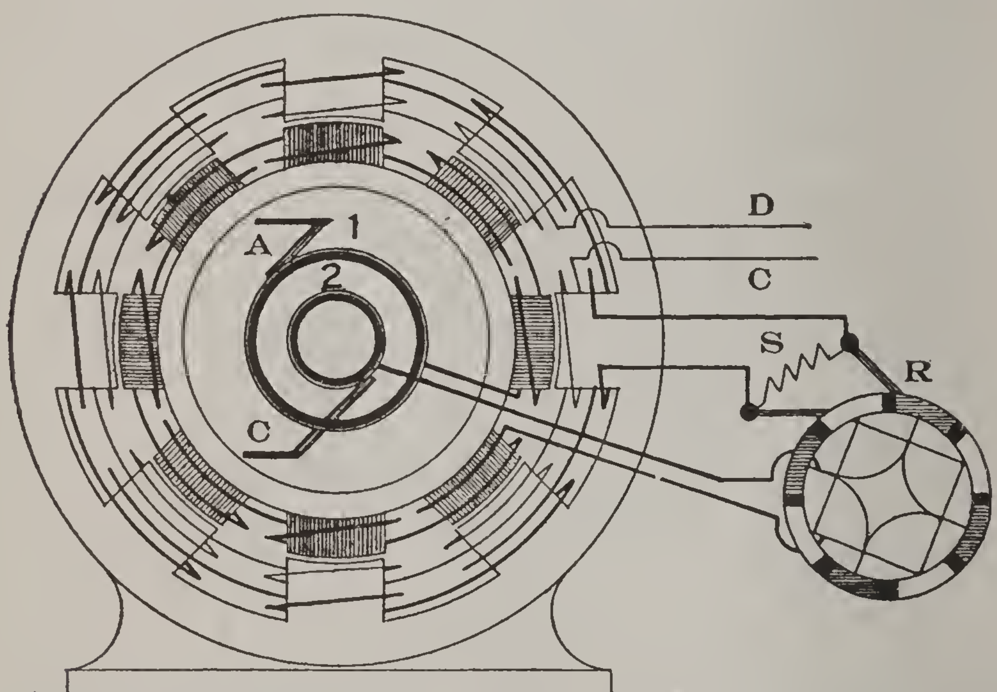


Figure 53

must be rectified so that, although it is variable in strength, the pulsations all pass through the fields in the same direction. For this purpose the rectifier R, Figure 53, is provided. This rectifier is fastened to the same shaft as the armature and revolves with it. All of the white sections of R are joined together by the wires shown as forming a square and the shaded by the wires shown as curved lines. The shaded sec-

tions connect direct to collector ring 2 and the white to the wire coming from the armature, as shown. The brushes shown bearing upon the rectifier are adjustable and are to be set so that at the moment when the alternating current is passing through the zero part of its waves, the connections are changed, i. e., one brush changes from a shaded segment to a clear one and the other vice versa. By this arrangement the current passing through the fields of the generator (stationary in this case) remains always in the same direction although that in the line is alternating. The main current can readily be traced, beginning at A, collector ring 1, armature, clear sections of rectifier, fields, shaded portion of R to collector ring 2 and the line, finally returning to A. The direct current field circuit is shown at D C.

The rectifying arrangement works quite satisfactorily as long as the load is of constant inductance. This is, however, only the case so long as merely incandescent lights are in circuit. When motors or arc lights are operated the current does not always coincide in phase with the normal adjustment of armature and rectifier and begins either to lag or lead, that is, the zero part of the wave occurs a little later or earlier and therefore the change of rectifier segments is made at a time when there is considerable current flowing, which results in severe sparking unless the brushes are constantly being shifted. For this reason the rectifier is not being much used at present.

It will be seen that by shifting the brushes the full width of a segment the direction of the current around the fields can be reversed. A variable shunt S can be

arranged by means of which more or less of the rectified current can be diverted from the field circuit.

In actual practice the generating coils of alternators are not wound upon projecting coils but laid into slots as indicated in Figure 54. Sometimes each slot contains only one wire; sometimes there are many. The number of slots per pole also varies. For two and three phase machines two or three windings are arranged either upon the rotating or stationary part. In Figure 54 there are three slots per pole and this armature is designed for three phase currents. The

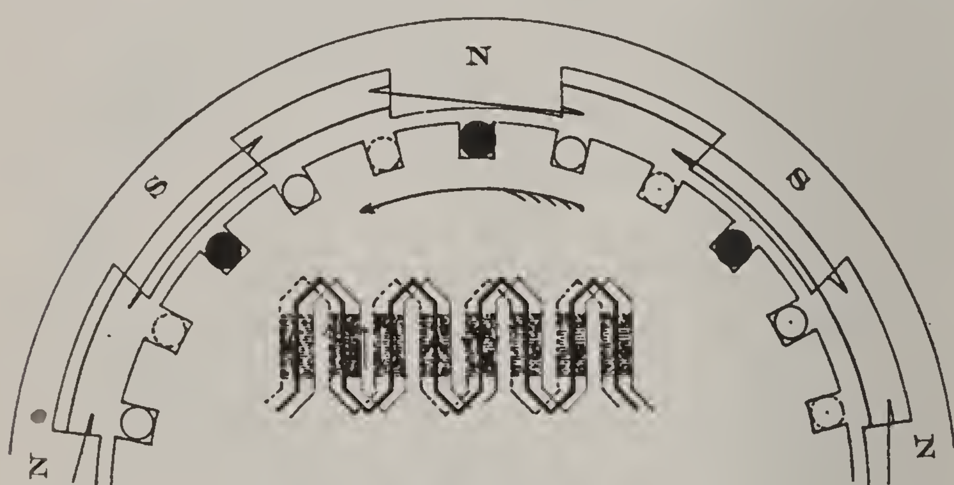


Figure 54

positions of the wires for one of the phases is indicated by the black circles. As these sweep around under the pole pieces the currents induced in each wire are in a different direction and to make all of them generate in series they are connected on the two sides of the armature as shown by the heavy black lines, where the arrows indicate direction of induced currents. The other two phases are wound into the empty slots in the same manner, and it can be seen that while the phase represented by the black circles

is at a maximum, being directly in the strongest part of the field, that at the right of it is increasing and the one at the left decreasing. These wires are connected to collector rings in such a manner that in the outside circuit they are in opposite directions, one wire always forming the return for the other two. A partial diagram of the winding is shown in the center of the figure.

CHAPTER VI

PRINCIPLES OF ELECTRIC MOTORS—DIRECT CURRENT

The reader will, no doubt, have noticed that there is no great difference between a dynamo and a motor and that there are about as many different types of one as of the other. As a matter of fact, any dynamo can be used as a motor and any motor as a dynamo, although as a rule less care is bestowed upon the manufacture of motors and most of them would operate at very low efficiency if installed as generators.

In the shunt dynamo we apply power to revolve the armature in the fields and the power required is proportional to the current flowing. If the armature is on open circuit we require no more power than is necessary to overcome the friction. It is, therefore, the reaction of the current in the armature against the fields which requires the power to overcome it. It follows from this that if we take the belt from a dynamo and arrange for an equal current from some other source to flow through the armature in the same direction we must obtain motion, but in a direction opposite to that in which the armature was revolved when generating.

Let us look at this a little more in detail. Figure 55 shows the armature and fields of a motor. Cur-

rent is flowing into the armature through the brushes. We have seen that the two halves of such an armature are in parallel and that the current magnetizes the armature, setting up poles as indicated by N and S. Arranged as shown in the figure, the S pole of the fields will attract the N pole of the armature and repel the S pole. This will cause the armature to move to the right and were it not for the commutator it would move only until the poles of armature and fields had aligned themselves. But as the armature moves the brushes change connections coil by coil and the

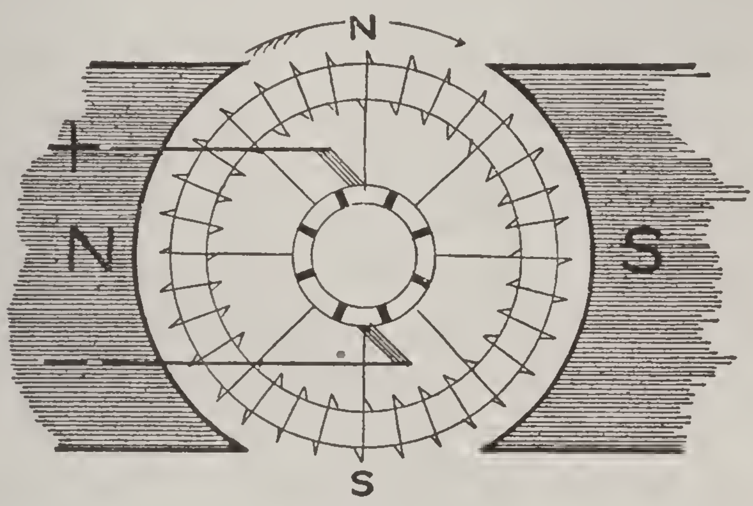


Figure 55

N and S poles of the armature remain always in the same position, thus keeping the armature always in motion in a vain endeavor to align itself and come to rest. Should we change direction of current either in field or armature, the motion would be in the opposite direction. If current through both fields and armature is reversed motion will continue in the same direction. The pull of the armature is governed by the current flowing in it and the strength of the fields.

Since the motor is the exact counterpart of a dy-

namo and its armature operates in a field precisely similar to that of a dynamo, it follows further that it must generate an E.M.F. just like a dynamo, and so it does, and this E.M.F. is always opposed to that of the dynamo from which the motor receives its current. This E.M.F. is known as the "counter E.M.F." of the motor and varies with the strength of field and speed of armature, or, in short, with the rate of cutting lines of force just as the E.M.F. of the dynamo does. The current which flows from the dynamo to the motor varies as the difference between the E.M.F. of the dynamo and the counter E.M.F. of the motor. Thus, if the voltage of the dynamo be 110 and the counter E.M.F. of the motor 105, the current flow through the motor will be due only to the five volts. The torque or pull of a *shunt* motor will depend upon the current, and consequently as a greater load comes on the motor, it must slow up until its counter E.M.F. is sufficiently reduced to allow the requisite current to flow.

If the armature of a motor have a very high resistance, it follows that its counter E.M.F. must be much lower than the E.M.F. of the dynamo in order that the necessary current may be forced through it. If with such an armature an additional load is thrown on, it must, of course, slack off in speed considerably in order to lower its counter E.M.F. sufficiently to draw the necessary current. The lower the resistance of the armature, therefore, the nearer constant the speed of the motor. This applies also to the resistance of the line. This fact is often made use of in regulating the speed of motors, an artificial, variable re-

sistance, known as a rheostat being cut into the circuit to control the speed.

So long as the motor is at rest, it has of course no counter E.M.F. If, at such a time the dynamo current were turned on, the armature of the motor would, up to the time that it acquired its proper speed and developed a counter E.M.F., present a circuit of very low resistance and be subject to an enormous current flow, which would speedily cause it to burn out. To prevent this a rheostat is always cut into the arma-

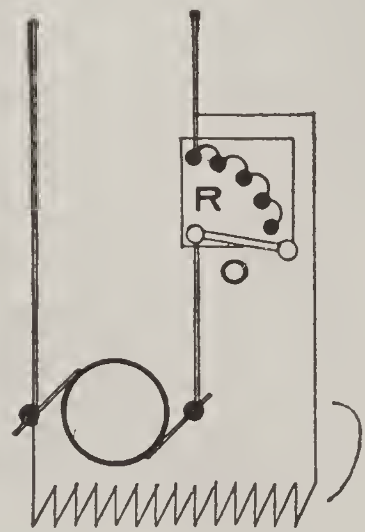


Figure 56

ture circuit. Figure 56 shows diagrammatically the circuits of a simple shunt motor. When the motor is to be started, the arm O of rheostat R is gradually moved, cutting out resistance.

The speed of a motor can be made to vary, first, by adding resistance in the armature circuit. This we have seen will tend to slow it down. Second, by increasing the strength of the field it can also be made to run slower. With a stronger field not so much armature speed is necessary to develop a given counter

E.M.F. and as this can never exceed the E.M.F. of the dynamo it follows that the motor must slow up. Conversely, by weakening the fields we can increase the speed of the motor, but if the fields are weakened too much, the armature may not be able to do the work and the counter E.M.F. fall so much below that of the dynamo that the armature will burn out.

The effect of a wrong position of the brushes is evidently quite different with motors than with dynamos. Suppose the brushes, Figure 55, to be moved ¼ turn in the direction of motion. This will throw the N and S poles of the armature in perfect line with the polarity of the fields, and in this case the armature would have to come to rest. There would be no counter E.M.F. and the rush of current would burn up the armature wires. Again, suppose the brushes to be moved one-half revolution forward or backward, the direction of motion will be reversed.

The magnetism of the N. pole of armature, of course, repels the magentism of the N. pole of the field just as it does in a dynamo. Hence with an increase of current through the armature which always follows increase of load, the neutral line is shifted in the opposite direction in which the armature revolves and, to avoid sparking, the brushes must be shifted just in the opposite way to those of the dynamo. The same considerations that apply to short circuiting coils in an active part of the field of a dynamo apply to motors. The position of least sparking at the brushes is not, however, the position of greatest torque. The greatest pull is obtained when the brushes are set somewhat back of the neutral. If the brushes are

shifted in either direction far from the neutral line, some of the coils will not be generating any counter E.M.F just as in the dynamo, and, consequently, if the motor is running empty, it will speed up. If the motor is loaded, the armature will not be able to pull the load and slow down and very likely burn up.

The maximum speed of any motor is that at which its counter E.M.F. most nearly equals the E.M.F. of the circuit. This speed can be approximately attained when the motor is doing no work.

The losses in the motor are due to the same causes as those in the dynamo. A certain amount is due to friction. There is a loss of potential due to the resistance of the line and a further loss due to the armature resistance. This in the armature, if excessive, will manifest itself by much heating.

If the fields are wound with a few turns of large wire instead of many turns of fine wire an unnecessarily large current will be required for magnetization. If a poor quality of iron is used in the fields, or if the air gap between pole-pieces and armature is too great, the magnetic circuit will be of low conductivity (see chapter on magnetism) and require unnecessary power to generate.

CHAPTER VII

TYPES OF MOTORS—DIRECT CURRENT

There are as many different types of motors as there are of dynamos. Any dynamo may be used as a motor and any motor as a dynamo, as we have seen in another chapter. It is merely a question of applying current properly.

In the matter of regulation, however, there is considerable difference. We shall begin our study with the oldest and now almost obsolete form—the constant current series motor. This motor is made only in small units and used only on arc light circuits. The amperage of an arc light circuit does not usually exceed ten amperes. To obtain even 5 H. P. with ten amperes would require a voltage of about 400 volts, hence it can readily be seen that such motors are not commercially practicable except in small units and then only when no constant potential circuit is available.

The torque or pull of any series motor, if the fields are not oversaturated, is proportional to the square of the current. Doubling the current doubles the strength of fields, and as the same current passes through the armature its strength is also doubled, hence the power of the couple is quadrupled.

We have seen in a previous chapter that the speed limit of any motor armature is that speed at which the counter E.M.F. is equal to the E.M.F. existing at its terminals. These two can of course only be equal when no current is flowing, i. e., when the motor is doing no work. As we are here dealing with a current which is kept at a certain value by the dynamo, we need take no precautions to keep the current from damaging the motor. If now such a motor be started with a load it will at once develop its full torque or pulling power, the maximum current being instantly available in fields and armature. The torque will also be constant since field and armature are of constant resistance. The counter E.M.F. of the motor has no effect upon the circuit except to require the generator to work at a higher pressure. The speed of such a motor will vary as the load put upon it. If the load be removed from such a motor it will increase its speed and oppose the dynamo E.M.F.; this in turn will be increased and again the motor speed will be increased in a vain endeavor to build up an E.M.F. equal to that of the dynamo. If this racing of the motor is not checked by an increase of load or a regulator of some kind it will continue to speed up until it flies to pieces. The speed regulation of this motor is usually accomplished by reducing the field strength as the load decreases and increasing it as the load increases. The methods employed are similar to those illustrated in Figures 40 and 41.

We may next consider a similar motor on a constant potential circuit. The torque in this case is proportional to the square of the current as above. But in

this case the generator is without control over the current. If current is turned on suddenly before the armature is in motion there is only the ohmic resistance of the line, fields and armature to prevent it from rising to an enormous value. In well designed installations these are all low and the result would be a burned out armature. Hence the resistance R, Figure 57, is provided. This motor loaded down will act as has been described under Principle of Motors, the arma-

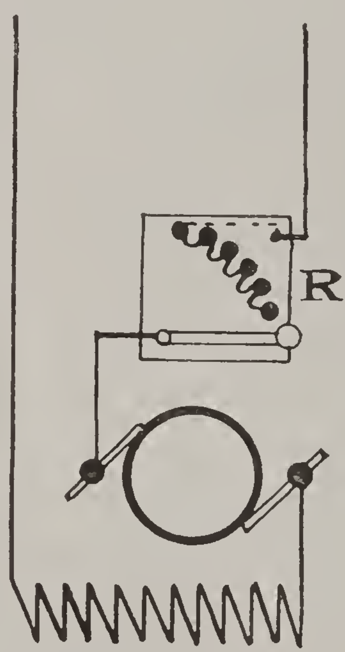


Figure 57

ture tending to run at a speed at which it develops a counter E.M.F. equal to the E.M.F. existing at its terminals. With a heavy load the motor must slow down considerably to permit the necessary current for doing the work to pass. As the load is removed the current flowing becomes less because the motor speeds up and the counter E.M.F. begins to rise. This in turn weakens the fields Weakening of the fields lessens the counter E.M.F. of the motor and consequently

it speeds up to make up for this. As the motor speeds up more and more the fields become gradually weaker and weaker, thus calling for still more speed in an endeavor to bring the counter E.M.F. up to the initial E.M.F. of the dynamo. This speeding up of a series motor without load will continue until the armature flies to pieces. For this reason such motors are as a rule used only where an attendant can be kept constantly with them.

As a rule this motor is used only in street railway work and on cranes, etc. In this case an attendant is necessary anyway. The motor because of its great starting power is best suited for this work, and any other kind of motor would moreover be entirely unsuitable, because very often the current is suddenly stopped or put on because of the trolley wheel leaving the trolley. With this type of motor there can be no current through the armature unless there is the same current through the fields. Consequently every rush of current (the armature being in motion, as it always is when the wheel for an instant leaves the trolley) is met by the proper counter E.M.F., which prevents undue current flow, and there is no need of regulation unless the speed of the armature has been much reduced during the time current flow was interrupted.

The motor most in use for general work is known as the shunt motor. The fields and armature of this motor are entirely independent of each other. In operating this motor it is necessary to see that full current is in the fields before any current is allowed to pass into the armature. The armature current

must then be turned on gradually so as to give the armature time to get in motion and develop the necessary counter E.M.F. before the full current is turned on. This is accomplished by means of the rheostat R shown in Figure 56. The speed of this motor is nearly constant under variable load within proper limits if it has been well designed and installed with low resistance in armature and line. It cannot be used in connection with street car work, principally on account of the inductance of its fields. The fields of a shunt motor always contain a great many turns of wire, and it requires some time for the current to attain its full value in them. If the current were cut off from such a motor for, say, a second and then applied again, as often happens in connection with trolley service, the fields would in that second have lost their magnetism and upon the connection being reestablished the motor would be running without fields and, of course, without its proper counter E.M.F. This would invite a very strong flow of current through the armature before the fields have time to build up, and furthermore a good armature without counter E.M.F. would offer almost no resistance and be equivalent to a short circuit and this would entirely prevent the fields from getting current so that either a fuse or circuit breaker would go out or the armature would burn out. To prevent accidents of this kind rheostats with overload and underload switches have been devised which entirely disconnect the motor if the current fails.

The compound motor varies from the shunt motor just as the compound dynamo does from the shunt

dynamo. A compound wound motor may, however, be used in two ways. If the current in the series winding is in the same direction as that in the shunt winding the fields will be strengthened as the load is increased. This will enable the armature to develop its counter E.M.F. with a lesser number of revolutions and therefore it will slow up. The power of a compound motor so connected will increase as the load is increased but the speed will decrease.

If the current in the series fields flows in the opposite direction to that in the shunt fields the magnetism in the fields will be lessened as the load increases. This will force the armature to move at a higher rate of speed in order to develop an E.M.F. equal to the E.M.F. at its terminals. If the series fields are properly proportioned to the shunt fields and the resistance of armature and line, the motor will run at a uniform speed with any load within its capacity. It will be noted, however, that the current through the armature with such a motor increases as the load increases much more rapidly than with an ordinary motor since it must make up for the deficiency created in the fields by the opposing magnetism. The capacity of two identical motors, one shunt wound and the other "differential," as this winding is termed, is therefore not equal, the differential motor having a much smaller capacity.

As the differential motor uses power to neutralize power, i. e., the current in the series fields acts against that in the shunt fields, its efficiency is lower than that of any other direct current motor and its use in general is not to be recommended except where great constancy of speed is absolutely necessary.

CHAPTER VIII

PRINCIPLES OF ALTERNATING CURRENT MOTORS

Many of the types of small direct current motors may be run on alternating current circuits. That this is true is readily apparent when it is recalled that changing the direction of flow of current in a direct current motor (both fields and armature) does not reverse its direction of rotation. When current flows through the motor in a positive direction, for instance, there is a certain attraction between those poles set up by the field current and those poles set up by the armature winding. If the direction of flow of current is reversed each of these sets of poles is reversed and the same attraction exists as before.

Every coil of wire wound on an iron core, as in the case of a field magnet, has a certain inductance, which, when an alternating current is sent through it, acts as a resistance and tends to cut down the current flow. It is due to this fact that the majority of direct current motors, especially the larger sizes, cannot be used on alternating current circuits. If a direct current motor were constructed without iron either in the fields or armature it would operate on alternating current as well as on direct current. This characteristic is taken advantage of in some forms of

integrating watt-meters which are suitable for use on either direct or alternating current circuits.

If two identical alternating current generators were run, one as a generator supplying current to the other as a motor, the one running as a motor would run in exact synchronism and at exactly the same speed as the one running as a generator, for every change in the force producing power in the generator would be reproduced in the motor. This can be more readily understood by a study of the effects in a simple case. Suppose two bi-polar machines each have an armature consisting of a simple loop the ends of which are

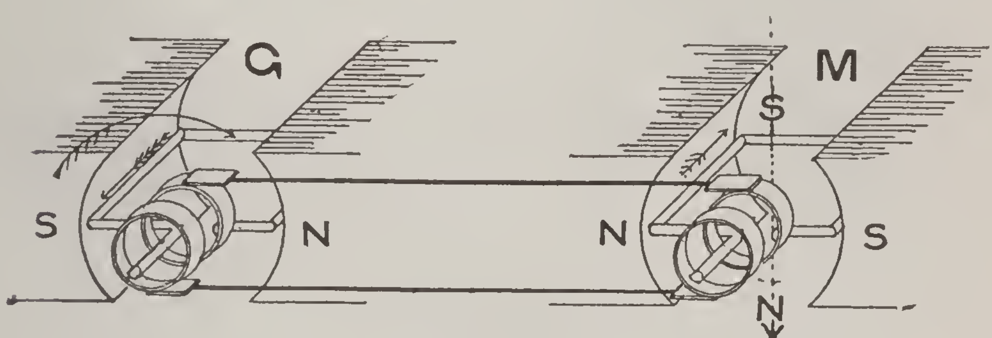


Figure 58

connected to two collector rings, as shown in Figure 58. The fields of both the generator and the motor must be supplied by direct current from some outside source. If the armature of the generator G is revolved to the right, as indicated by the arrow, current would be induced in the moving coil in the direction shown by the other arrow. This current flowing in the coil of the motor M would set up poles, as indicated by the dotted line S N, and these poles would be acted upon by the polarity of the fields, which is permanent, as shown. A north pole N will attract a south pole S and repel another north pole. This re-

sults in motion and the armature of the motor is revolved toward the left.

The successive steps for a half revolution are illustrated by the figures in Figure 59, where the figure at the left represents the various positions of the generator coil, 1, 2, 3, 4, 1′, as it makes a half revolution. The several figures at the right show the resulting condition and corresponding position assumed by the motor armature. 1 represents the position of the armature, as shown in Figure 58. At this point the generator coil is generating its maximum current. This current flowing through the coil of the motor

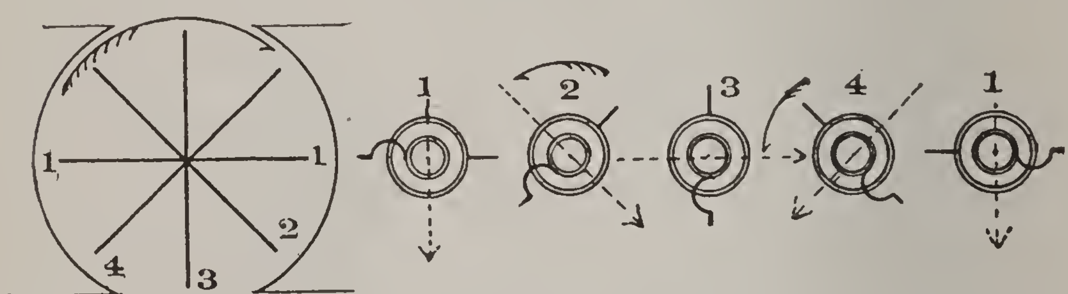


Figure 59

produces a field of force with a polarity, as shown in the head of the arrow, indicating an N pole, and as the generator armature is requiring at this point the greatest expenditure of energy to turn it so is the motor armature yielding its greatest turning effort.

When the generator armature has revolved to point 2 the conditions in the motor armature are as shown in 2. There is the same tendency to turn the motor armature as before, but as the current in the generator armature is decreasing so is the tendency to turn in the motor armature likewise decreasing As point 3 is passed the direction of the current produced by

and also the po-

x at point 4 the con-

are as shown at 4. It

the generator armat rent in the motor arma-
larity of the moto opposite direction, with the
ditions in the m between the armature and
will be notic epeated, and the motor armature
ture is no revolve in synchronism with and at
result t he speed as the generator armature.
field gle coil generator just described is in op-
will nd connection made to the motor armature
his armature is at rest, it will be quite evident
the motor armature will not revolve, for, when it
ssumes the position shown in 3, Figure 59, it will be
on a dead center and there will be absolutely no turning moment.

In order that the motor armature may continue to revolve it must have acquired some momentum to carry it over the dead center and it must also move at such a speed that it will always be at or near the dead centers when the dynamo current reverses. If it is not its movement will be opposed by the reaction between the poles of its armature and fields and come to rest. For this reason it is necessary to bring single-phase synchronous motors up to synchronous speed by some outside means before connecting it to the supply current.

Some polyphase synchronous motors are so designed that they will bring themselves up to speed if started under no load.

Owing to the fact that synchronous motors are not self starting and that some outside means must be

employed to bring them u ng
due to the further necessity
excitation they are seldom us
mercial work, their use being co us speed and
in such places where they can be use rrent field
conditions. ry com-

If the field excitation of a synchrono units
varied the power factor is also altered and ove
ble by varying the exciting current to pro
leading "current," this causing the motor to
the same effect on the line current as would be caus
by the introduction of a condenser. This characteristic is sometimes taken advantage of to increase the power factor on lines where it is low.

For the ordinary purposes for which motors are used neither of the motors just described is suitable. To be commercially practical a motor must be self starting and must be capable of starting under a load. It must require current from one source only, i. e., must be self-exciting. The "induction" motor fulfills these requirements, and is the form of motor in most common use on alternating current circuits.

The principles underlying the operation of a polyphase induction motor can be gathered from a study of Figure 60. In this figure the heavy black lined circles represent the wires of one phase, A, and the light those of the other, B, of a two-phase motor. These windings are placed in the slots of the stator as shown at the top of the figure and the small circle C represents one of the bars of a squirrel cage armature, as shown in Figure 62. This circle also marks in the different sections of the drawing 1, 2, 3, etc.

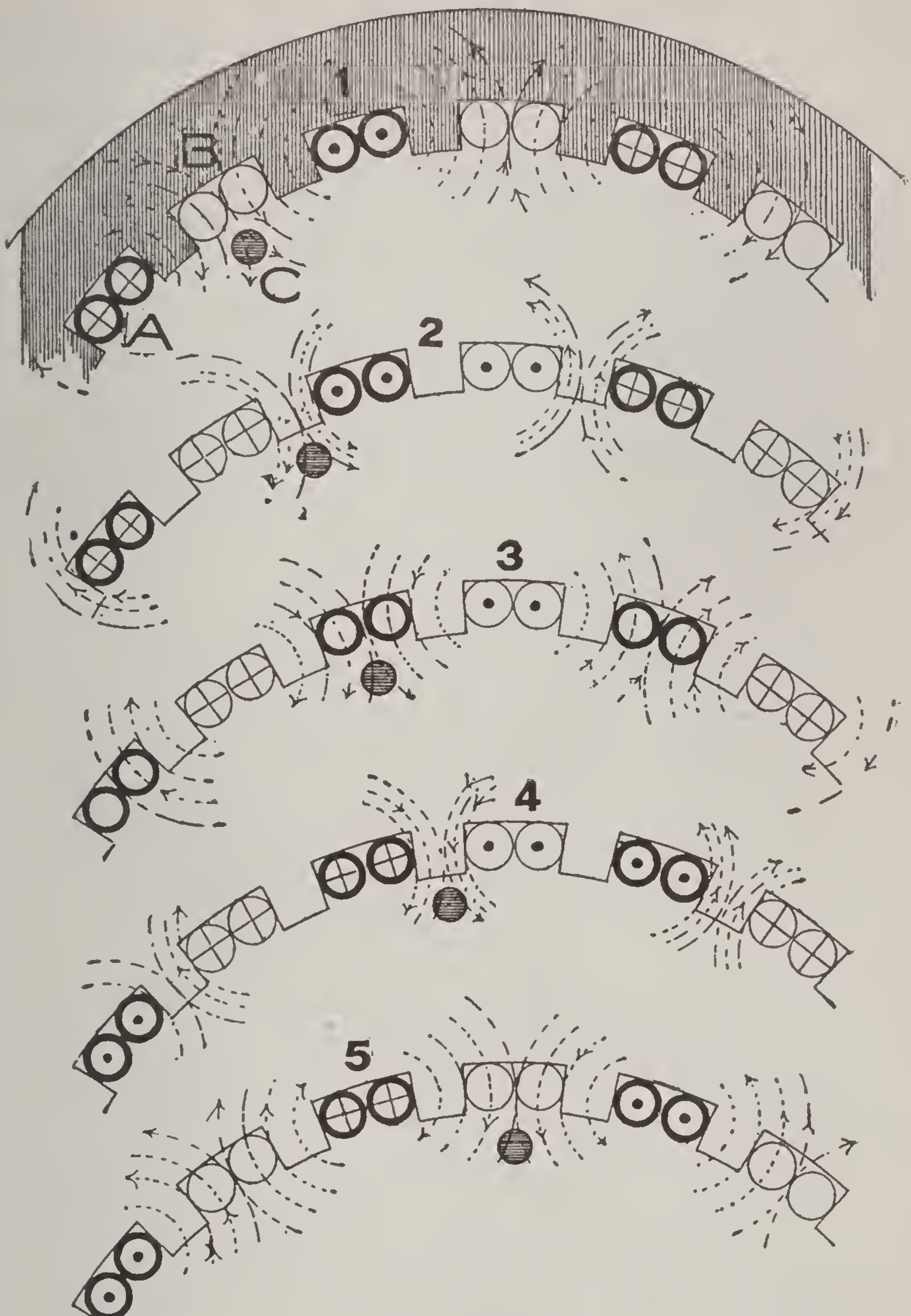


Figure 60

the position of a steadily advancing pole, in this case a north pole.

The wires A and B are traversed by two independ-

ent alternating currents which are, however, always in the phase relation illustrated in Figure 61 and indicated as to direction by a cross for positive and a dot for negative. In Figure 61 that portion of the currents represented by the sine curves above the base line may be taken as positive and those below it as negative.

To begin let us assume that the current in A is at a maximum, as shown under 1 in Figure 61; at the same instant the current in B is zero; under these conditions B will not be producing any lines of force

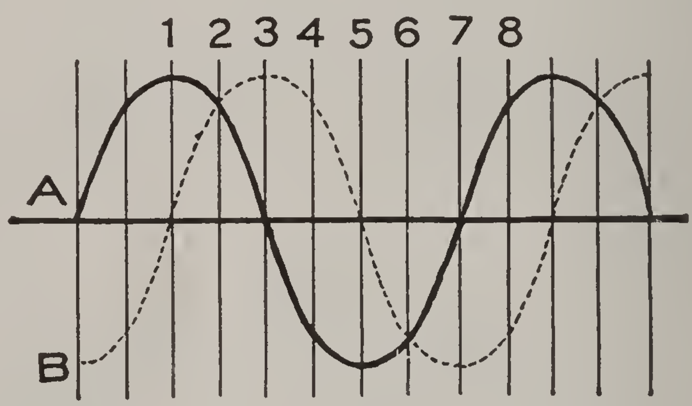


Figure 61

and A will be producing a magnetic field, as shown in 1 in Figure 60, the lines of force encircling the wire in which the current is positive (flowing away from the observer) in the direction in which the hands of a clock move. This produces a north pole at the wire C. A moment later the two currents assume the phase relation shown under 2, Figure 61, and the field becomes now as indicated at 2, Figure 60. The currents in both sets of wires now being in the same direction the lines of force expand and encircle both of them and the north pole is moved further to the

right. In another short interval A sinks to zero and B arrives at its maximum, as shown under 3, Figure 61. This in turn produces the field conditions, as shown at 3, Figure 60. As the two currents continue to rise and fall always maintaining the same phase relation (90 degrees apart), the field continues to change with them, as shown further in 4 and 5.

It will be noticed that all of the poles set up by the different convolutions are moving steadily from left to right, and it can also be seen that if we should reverse the two phases the poles would shift in the opposite direction.

If, while this shifting of poles is going on, the wire C should remain stationary it would cut the lines of force rapidly moving by it just as it would in any dynamo in which the lines of force were stationary and the wire moving. In this way currents would be induced in it. These currents would be in such a direction that the lines of force created by them would oppose the lines of force creating them. This opposition between the wire C and the field would result in motion if C were free to move. If C were to move at the same rate of speed as the revolving field it would cut no lines of force and no currents would be induced in it. It can in practice never move at this speed because it would then have no torque.

It can be seen from the above that the difference in speed between the revolving field and the wire C, or of an armature carrying many wires like C, must depend upon the load, and the greater the load the greater must be the difference in speed between the two. In other words, in order to carry a heavy load

such an armature must slack up in speed sufficient to allow of induction enough so that the reaction between the two currents may be sufficient to move the load. This difference in speed is spoken of as the "slip." If the load is too heavy the motor will simply come to rest and burn out.

It can also be seen that, if instead of a squirrel cage armature or rotor we provide one with a regular armature winding the induced currents can be brought outside of the machine and be controlled by resistance like those of any dynamo or motor armature This is often made use of in large motors.

Figure 62

The rotor of an induction motor acts like the secondary of a transformer and if it is at rest while currents are traversing the stator, the effect is the same as though a transformer were short circuited. For this reason these motors require enormous starting current for a short time, sometimes five or six times the running current.

In Figure 62 is shown the armature of an induction motor. The armature consists of a laminated iron

core with partially closed slots through the outer edge. Insulated copper bars inserted in these slots are bolted to rings on each end of the armature and are thus short circuited. This is called the "squirrel cage" type of armature owing to its similarity to the ordinary squirrel cage. The field is also formed of laminated iron cores with slots across its face into which the field windings are placed.

In some designs of induction motors the element which has here been called the "field" is made the revolving element, the "armature" winding being placed on the stationary part of the machine. The conditions, so far as the operation is concerned, remain the same whether the armature or field revolves but certain peculiarities in the design of the larger size motors, especially, make it preferable to have the field revolve.

The two terms "armature" and "field" have a rather indefinite meaning when applied to alternate current motors. The field is generally considered as that element which receives current from the line while the armature is that part in which current is induced. The more common term applied to these parts is "rotor" for the revolving element and "stator" for the stationary element, although owing to their similarity with a transformer the field is sometimes called the primary element and the armature the secondary element.

CHAPTER IX

TYPES OF MOTORS—ALTERNATING CURRENT

Single phase motors may be made self starting in a manner illustrated in Figure 63. This figure shows a diagram of the connections of a split phase motor. There are two sets of field windings and each has a different reactance, that is to say, one will permit a more rapid rise of current strength than the other.

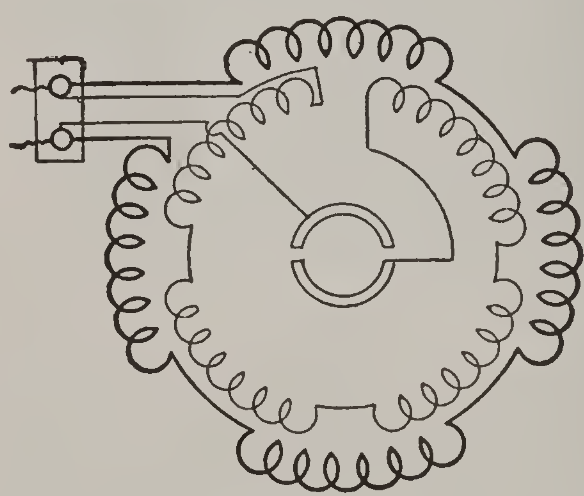


Figure 63

This action is as follows. The two semicircles in the center of Figure 63 surround the armature shaft. There is also a circular piece which revolves with the armature and which normally while at rest closes the circuit through the fine wire winding at the center. When current is turned on there is a flow through the

heavy winding and also through the fine, but there is considerable difference in phase between these currents and they set up a field, as already explained, for two phase motors. This causes the motor to start as a two phase motor and when it has attained its proper speed the circuit through the semicircle is opened by centrifugal force which causes the outer ring to spread out. The motor now runs as a single phase induction motor.

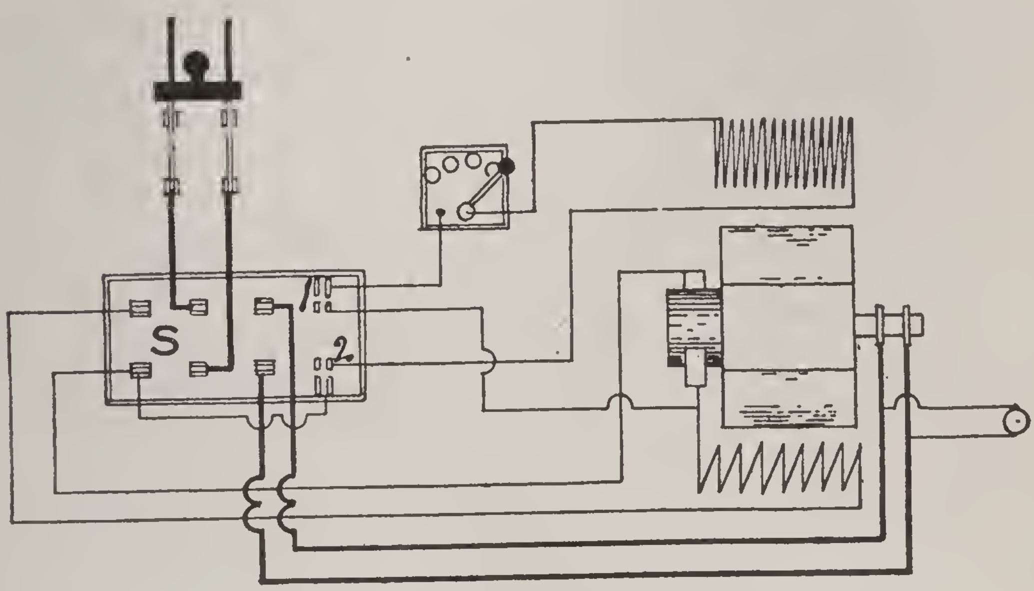


Figure 64

Another form of motor is shown in Figure 64. The armature contains a direct as well as alternating current winding. The motor is started by throwing the switch S (blades not shown) to the left. This sends an alternating current through the fields and armature and starts the motor. After it has come to speed the switch is thrown to the right; this sends the current through the alternating current side of the armature and also closes the direct current side through shunt fields and rheostat (the switch closes the connections

at 1 and 2). The motor now is synchronous with separately excited fields, the field excitation being furnished by the D. C. side of the armature.

The three phase motors up to a capacity of 5 H. P. are not usually equipped with starting devices. Such motors are self starting but require enormous currents when starting with load. Sometimes these currents are 5 or 6 times the running current. In order to allow such currents to be used at starting and still have adequate fuse protection when running the method shown in Figure 65 is generally employed. The

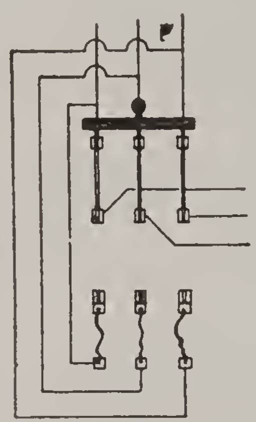


Figure 65

switch is thrown up to start and the current does not pass through the fuses. After the motor is running at its normal speed the switch is thrown downward, thus forcing the current to pass through the fuses and protecting the motor As an extra safeguard the switch in its first position is sometimes forced against a spring which would throw it out of connection if left there, thus assuring that the attendant will remain with it until the motor is running so he can throw it to the running position.

Polyphase motors are essentially constant speed motors. Any regulation of their speed is quite uneconomical. They are all self starting and all subject to the same heavy rush of current at starting, as noted

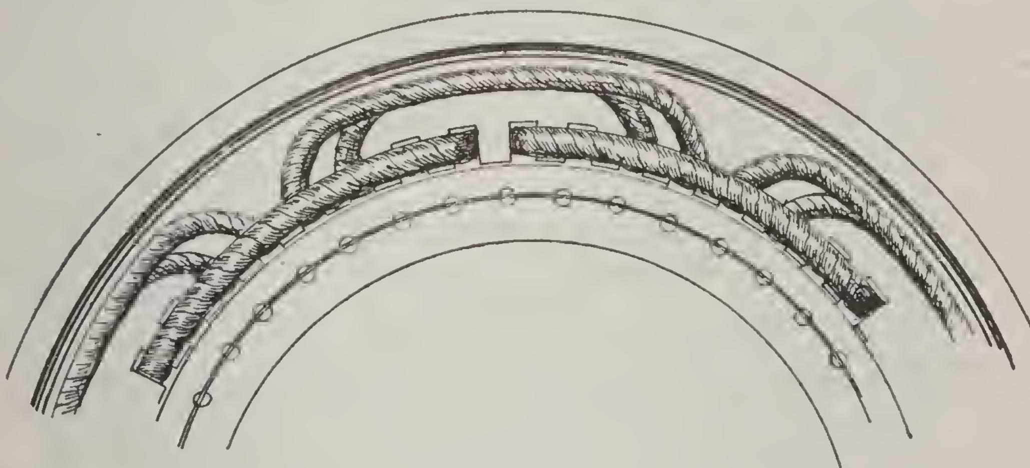


Figure 66

a[illegible]n the smaller sizes only the stator carries
less for some special reason the rotor is
The general appearance of the stator

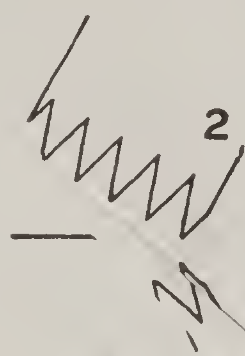


Figure 6.

winding is shown in Figure 66.
winding and the windings interla is a 3-phase
around. Diagrammatically such windill the way
represented as in Figure 7.
re usually

The windings of the three phases are shown in Figure 67. If we connect adjacent ends together we shall have what is known as the delta or mesh winding. If instead we connect the ends 1, 2, 3 together, we ob-

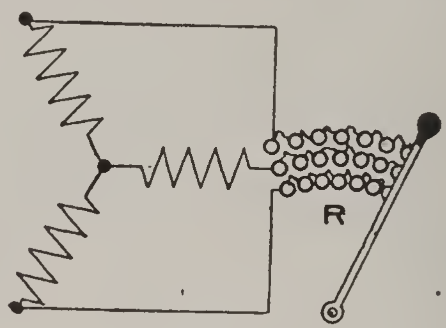
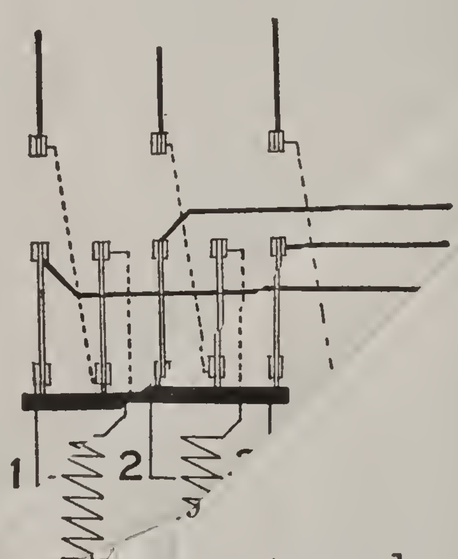


Figure 68

tain the Y or star winding If a motor connected up in Y be changed to delta it will require much more current. If connected from delta to Y it will require less current. Of course, in both cases the heating w



ch currents used, so that the
mus not be recklessly made.
change with char methods of arting induction mo-
change in conn One f the nsists in inserting
There are se.
tors in gen

resistances in the rotor circuit, as illustrated in Figure 68, at R. This is commonly used only with the larger motors. This resistance may be so proportioned that the starting power of the motor will be just as great with it in circuit as without it, and where great starting power is necessary this is a very useful method.

For the smaller and cheaper motors above 5 H. P., the method shown in Figure 69 is mostly used. While the switch is in the position shown the current must pass through the auto transformer R. The amount of reactance can be adjusted by connecting the wires, 1, 2, 3, at different points on R. The more reactance there is placed in the circuit the slower will be the starting of the motor. When the motor has attained sufficient speed the switch is thrown up and the current at full voltage goes direct into the motor.

CHAPTER X

DYNAMO OPERATION—DIRECT CURRENT

The dynamo room should be so situated that it is not exposed to moisture or the flyings of dirt and combustible material. There is nothing that will help induce an engineer to keep appliances in good working order more than a well ventilated and lighted room.

The larger dynamos are now generally direct connected, and should be placed upon foundations entirely separate from those of the building. This precaution is due principally to the vibrations caused by the engine. Where dynamos are belt driven there is very little vibration, unless the machine is entirely too heavy for the flooring upon which it is placed.

Whatever the power may be, whether steam, water, gas or gasolene, it is of the utmost importance to see that the prime mover operates as steadily as possible. The slightest fluctuation in speed will show in connection with incandescent lights. For this reason it is preferable to have the engines used for the lighting entirely separate from all other work that may be going on. This, of course, does not apply to factories, where only an indifferent light is required, as much as for central stations, where power is being sold.

If belt driving is necessary the machinery should be arranged that the belting may run as near horizontal as possible and the direction of rotation should

Figure 70

be such that the belt will pull on the under side. This allows the slack of the belt to hang downward on the

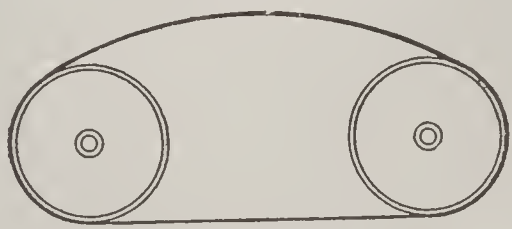


Figure 71

upper side and increases the arc of contact, as illustrated in Figure 70, whereas a belt operating as that

Figure 72

shown in Figure 71, by its slack decreases its arc of contact with the pulleys. Whenever it is necessary to arrange belting as in Figure 72, it becomes necessary

to keep the belts very tight. This is apt to result in hot bearings and also increases the amount of power necessary to operate.

It is best to choose belting that is considerably heavier than would be absolutely necessary to do the work. In order to obtain a certain amount of work from a belt there must be a certain pressure exerted by the belt upon the pulleys. This can be obtained by stretching a small belt very tight, but is far better obtained with a much larger belt operating with considerable slack. Such a belt will last much longer and will need very little attention, while the smaller will need continually to be tightened. The smoothest side of the belt should be run next to the pulley, as it makes the most perfect contact. The face of the pulley should be smooth, as all roughness tends to wear the belt and does not add a bit to the adhesion. Wherever practicable it is best to have belts made up endless; especially where the speed is quite high. With slow speed belting the lacing will not cause much annoyance, if it is well done.

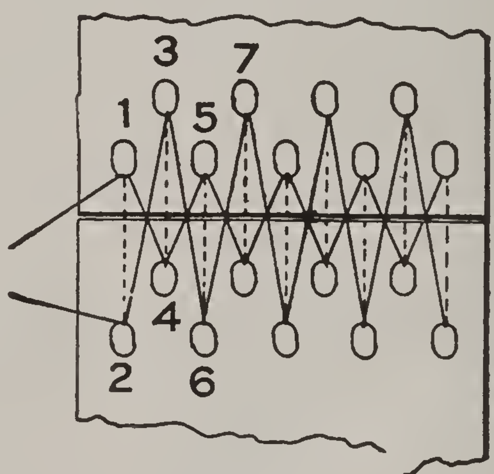


Figure 73

A good method of lacing is shown in Figure 73. The holes should be made rather oblong, as shown, as in this way we avoid cutting away so much leather. On no account should any laces be run crosswise of the belt on the side next to the pulley.

In placing belts it is always best to put the belt upon the smaller pulley first. Never allow oil to come in contact with rubber belting. Use only tallow or castor oil on leather belting. Grease can be removed from leather belts by the use of turpentine.

The generator or motor should always be provided with a sliding frame, so that it can be adjusted to suit the belt from time to time. If the belt is properly arranged, there will be some lateral play possible at the generator shaft; this is essential to smooth running and helps to secure even distribution of the lubrication.

The tension on all belts that are run tight should be relieved when the belt is not in use.

Double belts should not be used on pulleys of less than three feet diameter.

The proportion between two pulleys close together should not be greater than 6 to 1.

If one is limited to a certain width of belt the power can be increased by increasing the diameter of both pulleys in the same ratio. This will not affect the speed of the machinery, but will increase the speed of the belt and hence its power in the same ratio that the speed is increased.

The width of a single belt can be found from the following formula:

$$W = 1200 \times \text{H.P.} \div V$$

where W is the width of the belt in inches and V the velocity of belt in feet per minute. For double belts, use 800 instead of 1200. This formula will give belts of ample size and, if necessary, much smaller belts can be forced to do the work.

STARTING-ARC DYNAMO

Before attempting to start the dynamo the circuit should be tested out to see that it is complete. If this is found in order, the belts should be examined for tightness; the bearings should be well oiled; all iron tools, etc., should be removed from proximity to the machine lest they be attracted by the magnetism that will be developed and cause injury It will also be well for the operator to leave his watch, unless it is shielded against magnetism, as far as convenient from the dynamo. Many watches are brought to complete standstill by being brought too close to the fields of a powerful dynamo.

These things all being in order, the dynamo may now be set in motion, and it should now be so shifted on the sides that the armature has considerable lateral play. This indicates that the belt is in proper position and also helps to distribute the oil and keep the bearings cool.

If the machine operates at very high voltage, an insulated wooden platform should surround it on all sides, and this platform should be so placed and of such dimensions that no one can touch the machine without standing upon this platform This platform will be of no use unless it is kept perfectly dry, and to assist to this end should be well filled with shellac.

It will also be well for the operator, especially if he be a novice, to provide himsef with rubber gloves, and these also to be effective must be kept dry inside and out. As a further precaution, the operator should make it a rule while working on pressures above 220 volts, to touch bare metal parts with one hand at a time only. If this precaution is observed and if the body is kept well insulated from the ground there will be but little or no trouble experienced from shocks.

If the frame of the machine is grounded it will help to make things safer for the attendant, but will place a greater strain on the insulation. It will then be impossible for any one to obtain a shock by coming in contact with the frame, but greater care must then be exercised to avoid touching bare live parts and the frame at the same time.

Under no circumstances must one ever touch high potential wires while standing upon wet ground, boards, cement, metal connected to earth or upon anything that is not known to be a good insulator.

The regulator should now be examined to see that it is in proper working order and runs smoothly. Next place the brushes in position so that they bear properly upon the commutator. Before doing so, note that the armature is running in the direction called for by the position of the brushes. If it is not, one or the other must be changed about.

The plugs may now be inserted into the proper holes on the board. If there is sufficient residual magnetism in the fields the machine will begin to generate and, by noting the ammeter, the rise in current can be observed. If the residual magnetism is weak or en-

tirely absent, as sometimes occurs in new machines, or such as have been idle for a long time, it may not build up with all of the lights in the circuit. In such a case it is best to start the machine with one or two lights in circuit and when the current has attained to its full value to open the circuit and force current through the other lamps.

If there is no residual magnetism whatever, even this expedient will not suffice to start generation and current from some outside source, either from another generator or from a battery, must be caused to flow around the fields. Only a very small amount of current is required for this purpose.

It is most important, however, that the current from such a battery flow around the fields in the same direction as the current from the armaure would flow. If this is wrong in the first trial, it is but necessary to reverse the battery connections. Sometimes a machine can be started generating by striking the metal of the fields with a hammer in a gentle way.

When the machine is fully started, the next point of importance is to see that the polarity is correct. Unless the current enters the arc lamps at the proper terminal, the lower carbon will be consumed at the fastest rate and will, in a short time, burn down to the carbon holders, which will in turn be speedily destroyed. If the polarity of the machine is wrong, it can be corrected by changing plugs, as explained under switching, or the polarity of the fields be reversed, or the leads to the armature changed, as indicated, in chapter on current generation.

Other methods of determining the polarity are given

elsewhere, but the only one generally used in a case like this is that of observing the arc lamps. The positive carbon will heat to a greater extent than the negative and consequently will remain warm longer and also, if the lamp is burning right, the brightest light will be thrown downward, while if the other way a bright light and strong shadows will be thrown against the ceiling.

If there are more lights on a circuit than one machine can handle, two may be connected in series as shown in Figure 74. In such a case the regulator of

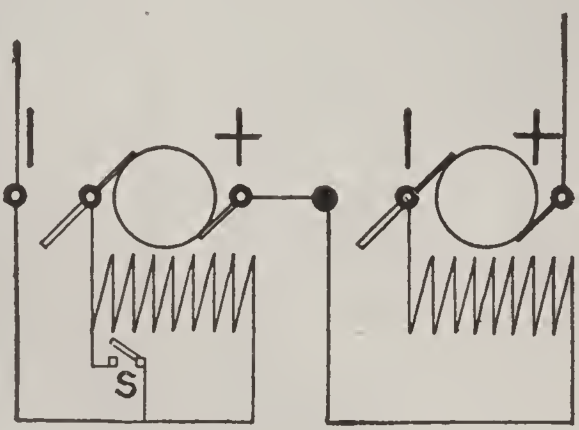


Figure 74

one machine is generally cut out and the brushes set for the highest potential at which this machine will operate well. The regulator on the extra machine is then depended upon to take care of the variations in the number of lamps cut into the circuit.

An expedient sometimes resorted to when a number of circuits are run from one machine as illustrated in Figure 75 and when there is an open circuit in one of them, is to cut out the bad line for a time by the plugs indicated by dotted lines at P, until the lights in the other circuit are burning full, then suddenly with-

draw the plug. This throws the whole accumulated force of the machine into the bad line, and if there is any possibility whatever the current will jump the bad place and often times operate the circuit successfully thereafter. This practice is known as "jumping in," and should never be resorted to when any other method is available, as it may ruin the dynamo or cause fire or a breakdown of the insulation somewhere along the line.

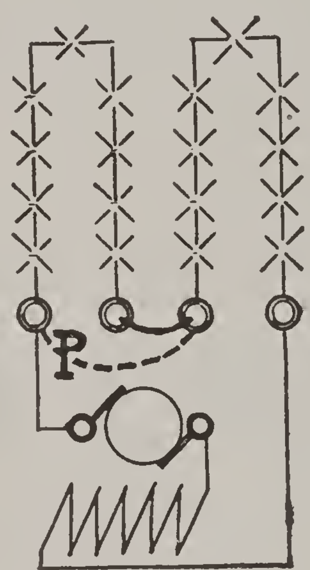


Figure 75

To shut down the dynamo we close the switch shown at S, Figure 74. This shunts the current around the fields, and leaves them wtihout magnetism, thus causing the current to sink to zero. On no account except that of extreme emergency must a series circuit operating at high potential be broken suddenly. Such an interruption causes an enormous rise of potential for a very brief interval, which very often breaks down the insulation of the machine. The arc which follows the plug when it is suddenly withdrawn, is also often dan-

gerous to the operator. If, however, such a circuit must be opened it should be done with a rapid motion and the operator should station himself so that the end of the plug or wire cannot strike him.

STARTING SHUNT DYNAMO

In latter day practice it is very seldom that a shunt dynamo is used with variable potential or constant

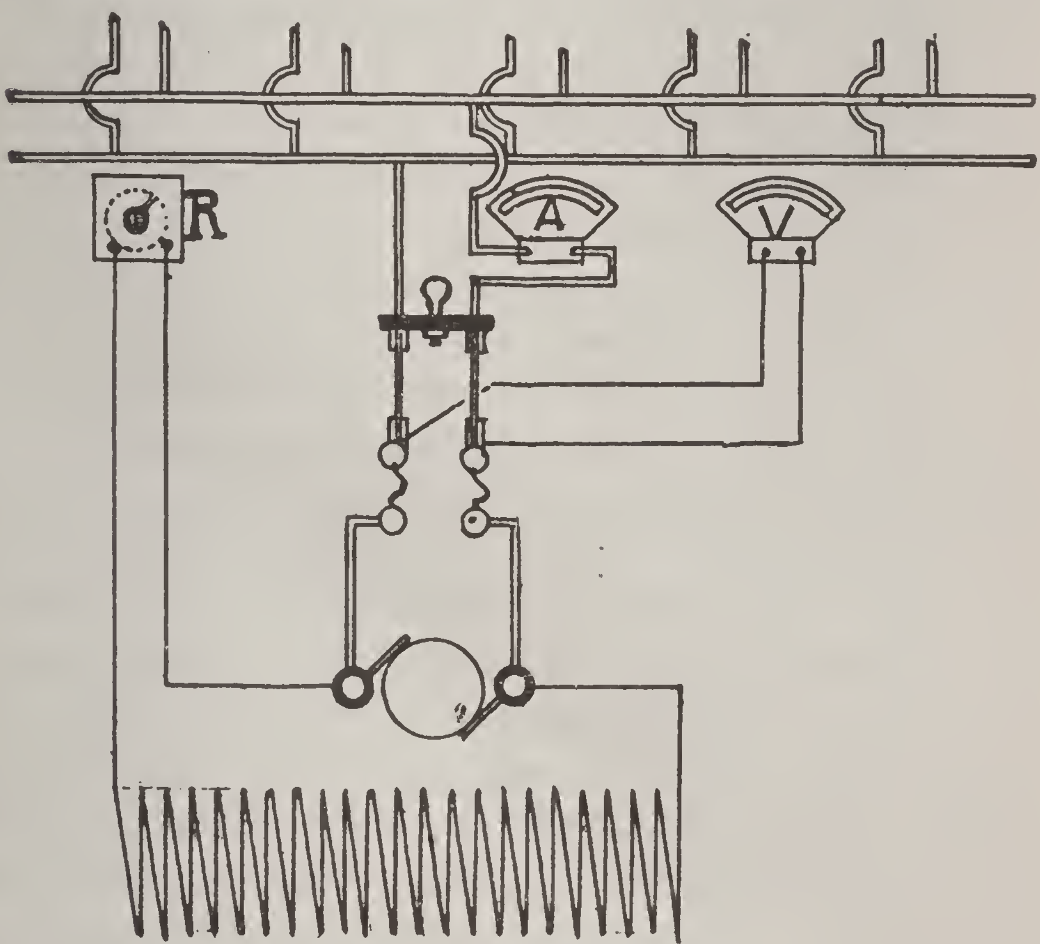


Figure 76

current systems. Such machines are limited to constant potential work and variable currents. The connections of a shunt dynamo and switchboard are shown in Figure 76. The same general considerations that apply to arc machines also apply here.

To start the generation, we first disconnect the machine entirely from the circuit. This is not always necessary, as many machines will build up successfully with the whole load connected. Nevertheless, however, it is safer to disconnect the load. When the machine has been set in motion, we observe the voltmeter and by means of the rheostat R regulate the current through the fields, so that the voltage gradually approaches its proper value and remains stationary. When this point has been reached the main switch can be closed and the lights will burn.

Unlike the series arc machine the shunt machine can do nothing while there is a short circuit on the line. There being no regulator the current immediately rises to its highest possible value and the pressure of the dynamo sinks to zero approximately. This machine cannot be started while it is connected to a short circuit, because all of the current generated will flow through this "short," which acts as a shunt to the fields. The "short" coming on while the machine is working wlil cause a momentary rise in current strength; it will also act as a shunt to the fields and deprive them of all current, thus finally reducing the E.M.F. of the machine until no more current is generated If the armature is wound so as to stand this current for a fraction of a second, it will do no harm to the dynamo.

In large installations it is customary to operate a number of dynamos in parallel. During the day, when the load is light, it will be taken care of by one of the dynamos and as the load increases more machines will be connected to the board to help out the

first one. If we have nothing but plain shunt machines, it is not advisable to attempt operation in parallel. It is practically impossible to keep two shunt machines at the same potential, and the one having the higher voltage will take the greater part of the load and also, when the difference amounts to as much as a few volts, run the other as a motor. This accident occurs frequently, and generally with so little disturbance that the attendants know nothing about it unless they happen to observe the belting or ammeters.

When a number of plain shunt machines are to work on the same installation, it is best to divide the system and give each machine a share of it. If this cannot be done, the voltage of the two machines must be constantly watched and adjusted by means of the rheostat.

For operation in parallel it is customary to provide compound dynamos. The arrangement of the wiring on such machines is such that when one machine takes more than its share of current it strengthens the fields of the other and thereby causes the potential of the other to rise until it draws its share of current. Compound machines when properly designed and driven by good engines, can be operated together with perfect freedom, no matter what the difference in capacity of the machines may be.

The connection and operation of two or more compound machines can best be understood if we refer to Figure 77, which shows the machine and switchboard connections of two such machines. It is essential to see that the ammeters A are cut in, as shown in the

diagram. If they are cut into the same side as the compound winding, the indications will be very unreliable, since the current from this side of the machine has two paths through which it may flow to the board; one through the fields of the other machine and one through the main of its own dynamo. The equalizer

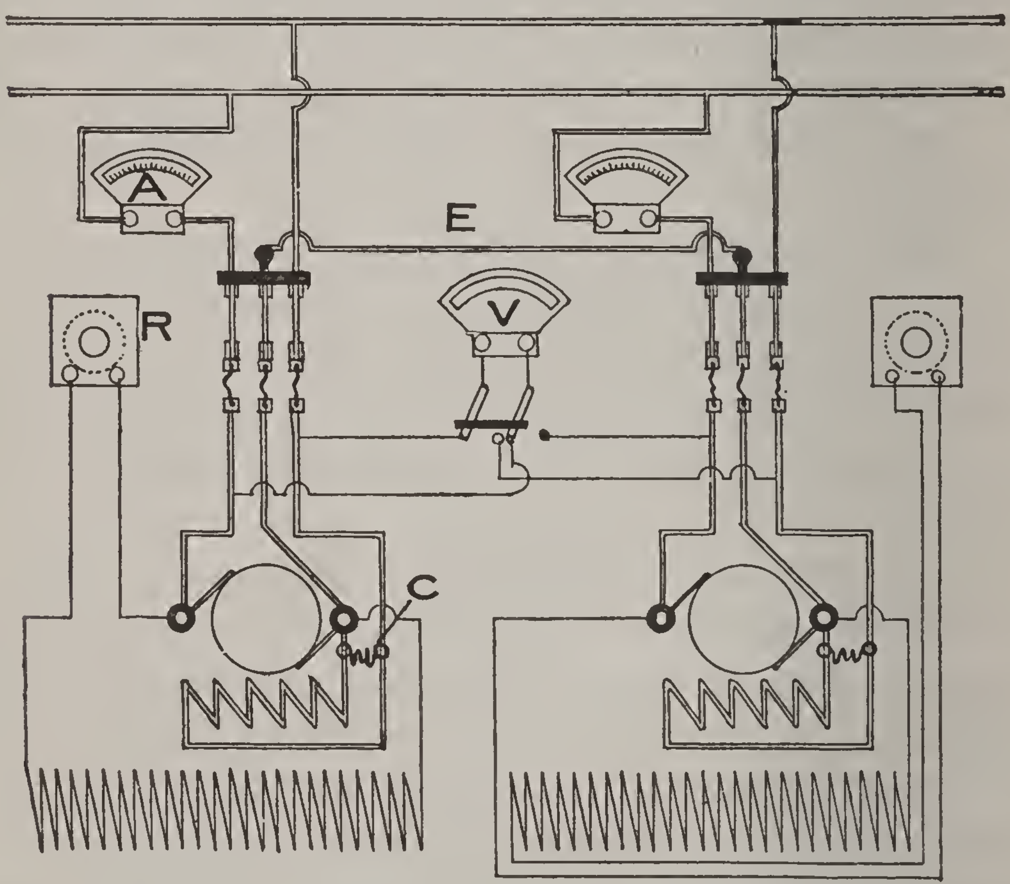


Figure 77

wire **E** should be of ample size, the lower the resistance of this wire the closer will be the regulation or the two machines. The main switches of the dynamos should be so arranged that the equalizer will be connected slightly before the other two wires are and on no account later. In order that such dynamos may work at their best, they should be run at exactly the

proper speed. If this is not the case, the relation between the shunt and compound winding will be disturbed. If, for instance, the machine is run above its intended speed, the magnetization of the fields will have to be below the usual point of saturation, and in this case the magnetization due to the series current will be greater than it should be and the rise in voltage higher than intended. If, on the other hand, the speed is much below normal, more resistance will have to be cut out of the field circuit, and thus the fields may be saturated by the shunt winding alone, so that the series current will have far less effect than it was intended to have, and the rise in voltage as the load increases will not be sufficient.

Many machines are provided with resistances placed in parallel with the series fields, and by means of these the series fields can be strengthened or weakened and in a measure adjusted to make up for variations in speed if they are unavoidable. The location of such resistances is indicated at C.

It will be well also to observe whether the series current circulates around the fields in the same direction as that in the shunt winding. If it does not, the series winding will have the opposite effect of that intended, and there will be trouble and sparking at the brushes and a large falling off in pressure as the load is increased.

To start a plant of compound dynamos we begin with a single machine. When this has been brought up to speed and is running smoothly, we close the circuit through the fields by means of the rheostat R and adjust this resistance until the dynamo gives the re-

quired voltage. It is better always to see that R is high at the start and gradually cut resistance out of it than to start with the resistance in R low. After the voltage is about up to its normal, we close the main switch. This, if there are many lights or motors using current, will result in a modification of the pressure and we must again adjust R until finally it comes to a steady value at what it should be.

If a load heavier than one machine can carry is likely to be found at the start, some of it had best be disconnected or circuit breaker or fuses may go out and cause delay.

After the first machine is started the second is brought up to speed in the same way and the voltage brought up as near as possible to that of the first machine when the main switch may also be thrown in. When this is done, it will be necessary for the attendant to observe the ammeters of both machines carefully and quickly adjust the rheostats so that each machine will receive its proper share of the current. It must be borne in mind that the machine with the higher voltage will take the greater part of the load, and if sufficient difference of potential develops between them it will run the other as a motor.

Before a newly set up machine is thrown in with another, it should be tested for polarity. In order that they may operate properly, similar poles of all machines must connect to the same bus bars. Two simple methods of testing for polarity are illustrated in Figure 78. At the left two lamps of the voltage of the machines are connected between the dynamos to be started and the bus bars, as shown. When the dy-

namo to be thrown in is up to voltage, the pressures of the bus bars and this dynamo must balance, and there can be no noticeable current flowing through the lamps. If, however, the polarity of the new dynamo is different from that of the others, the voltage of the system will be double that of one dynamo and the lamps will burn at full candle power. If the lamps

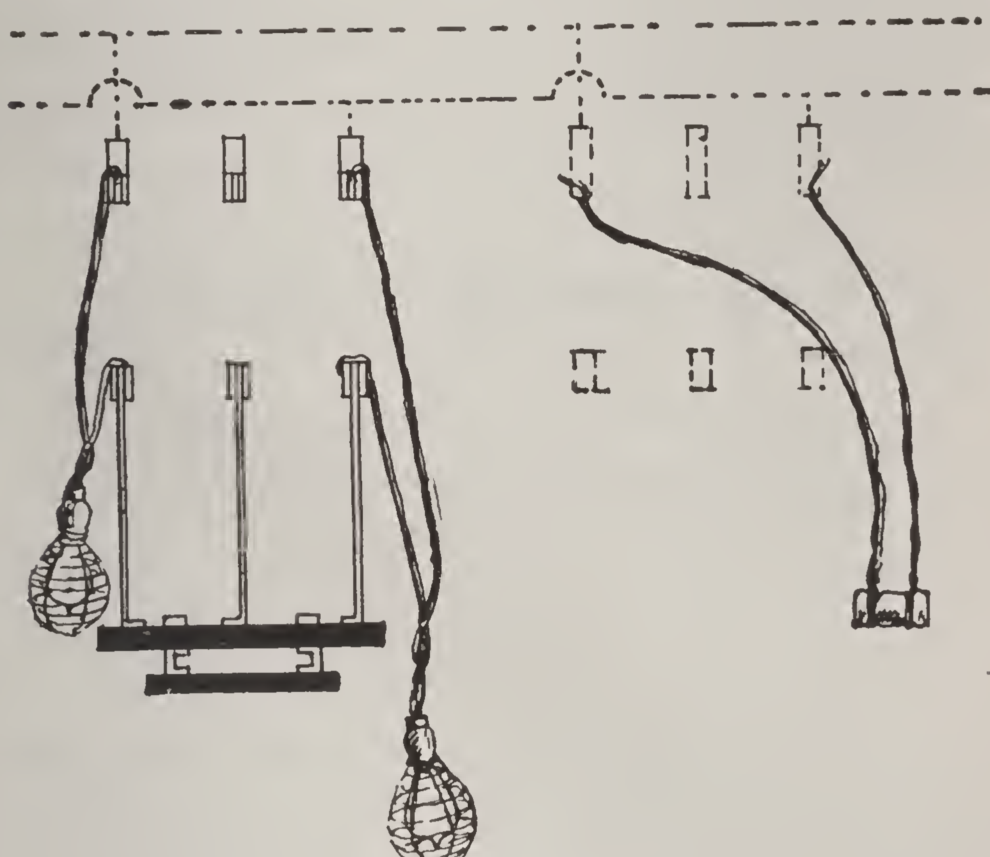


Figure 78

are dark, the polarities of the dynamos are correct for parallel operation.

In lieu of the lamps the test can be made by inserting one wire from each pole of the dynamo into a cup of water and noting the bubbles that form. If the polarity is correct the bubbles will form at the same pole of the switch on both machines. To avoid making

short circuits with this test, the bare ends of the two wires may be wrapped about a piece of wood about an inch long and the whole immersed in the water. Connect the same wires, one at a time, to the same poles of both switches and see that the bubbles come from the same wire.

A switch board arrangement often used with either shunt or compound machines, when engines regulate poorly, or in machine shops and other places where trouble from grounds or short circuits on large motor units are frequent occurrencies, is shown in Figure

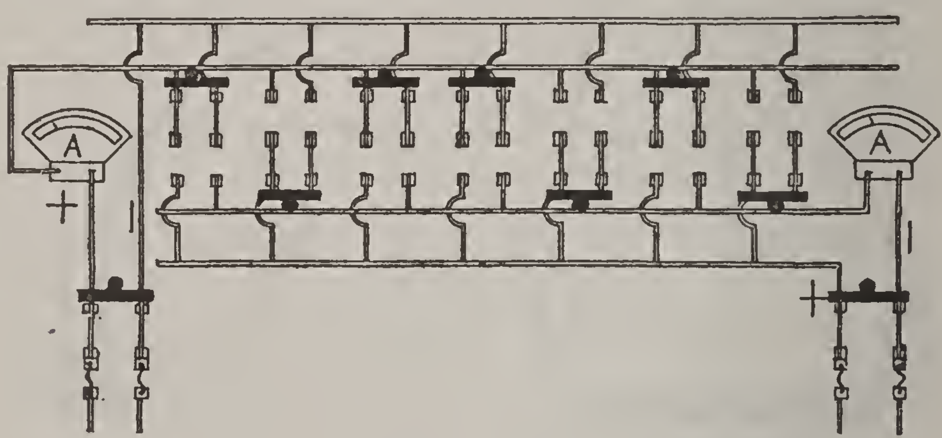


Figure 79

79. In many machine shops, for instance, the capacity of the motors connected is four or five times as great as that of the generators. The assumption is that only a small part of the motors will ever be operating at the same ime. When, however, the motor load exceeds the capacity of the generator, as it sometimes does, the generator fuses blow and place the whole installation in idleness. This is also likely to occur in case of trouble on a single large motor, such as are used for metal saws, etc. For the above reasons it is preferable to divide the plant into sections, as

shown. It will be noticed that any or all of the load may be thrown onto either set of machines by means of the throw over switches in the center row. Any desirable division of the load can thus be made. Office lights, for instance, can be separated from the large motors that are constantly disturbing the equilibrium of the lines.

In transferring motors from one machine to the other it is necessary to allow time enough for the automatic release to operate before the switch is closed on either set of bus bars, otherwise the motor is likely to be subject to a severe rush of current if its speed has fallen off much in the interval. If the motor is running light and has great momentum, the switch can be thrown over quickly without much fear of disturbance.

Shunt or compound dynamos if running singly, and if not supplying motors, may be shut down by simply shutting off the engine and letting them come to rest. If, however, there are motors connected to the dynamo, these must be disconnected before the voltage of the dynamo is allowed to go down. A motor heavily loaded may stop entirely when the E.M.F. at its terminals drop off, say twenty-five per cent. It will then be without counter E.M.F., and the armature will form a dead "short" which will blow fuses. The automatic release on the rheostat must not be relied upon in a case like this.

If there are several dynamos operating in parallel and one is to be shut down, it must be disconnected from the switchboard while nearly at full pressure. The pressure may be reduced only sufficient to trans-

fer the greater part of the load upon the machine which is to remain in service. If it is reduced more than this, the dynamo will be run as a motor by the other machine.

COMPENSATORS

Compensators, equalizers, or balancing coils are used in connection with high voltage generators to allow of the operation of lights or other devices at half the voltage of the dynamo. They also come in

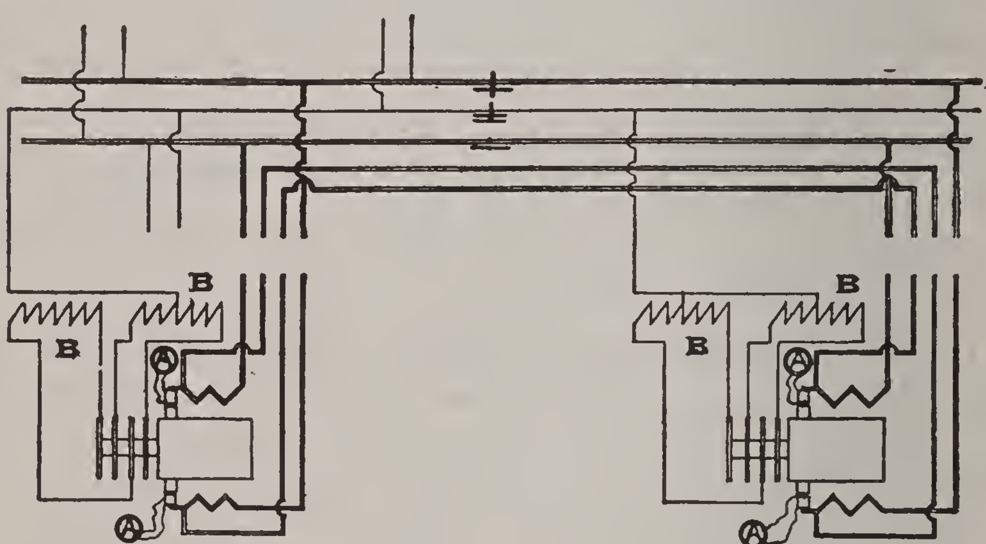


Figure 80

convenient for the operation of variable speed motors since they make two voltages available.

Figure 80 shows the connections of the system used by the Westinghouse Co. The armature of the dynamo is connected so that it can produce both alternating and direct currents. The main current is direct and there is just A. C capacity enough provided to take care of the unbalanced portion of the load, which is usually estimated never to exceed 25 per cent of the capacity of the generators.

All full voltage apparatus is connected to the + and — buses, and the half voltage equally distributed from the neutral and the two outside wires, so that the load will always be balanced as near as possible. The balancing coils B have the appearance of transformers, but carry no secondary winding. Their object is merely to provide a point at which only half of the voltage of the generator shall exist. Once properly connected they require no further attention except

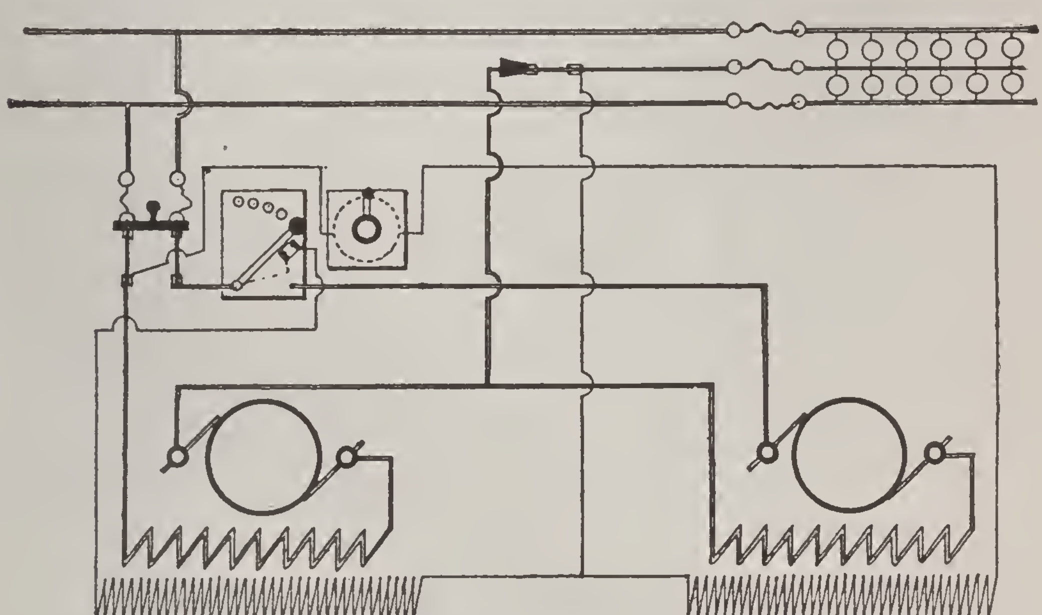


Figure 81

to see that the load is not unbalanced beyond their capacity.

As more or less of the load may come on either side of the dynamo the compound winding is divided between both sides of the generator, which makes it necessary to run two equalizer wires, as shown. An ammeter for each dynamo lead should also be provided. Volt meter and shunt field connections are not shown in this figure, as they are the same as with ordinary generators.

The connections of a balancing set as arranged by the Western Electric Co. are shown in Figure 81. Here two differentially wound motors are connected to the same shaft, so that they must run at the same speed. So long as the same number of lights are burning on both sides of the neutral wire the current through both motors is the same, and they perform no work, but keep in motion.

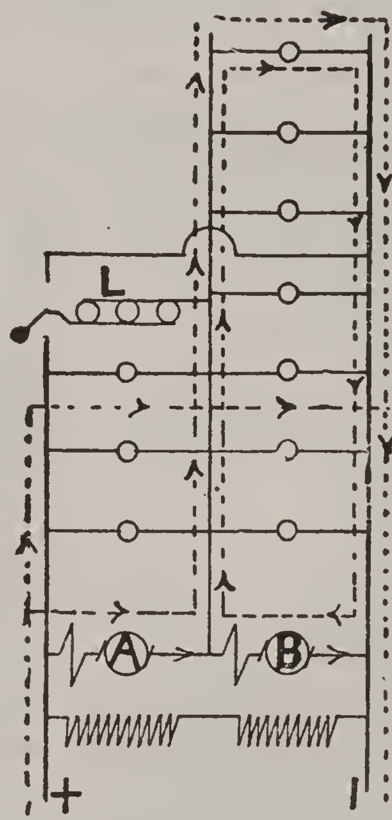


Figure 82

The action of the set can best be comprehended from observation of the elementary diagram, Figure 82. With the load unbalanced as shown, current from the generator will pass through motor A and supply some of the excess load on the opposite side. As this current is in opposition to the shunt fields, it will weaken the motor fields and hence speed it up. This speeding

up will also affect the other motor, the fields of which are not weakened, and hence cause it to act as a generator, thus helping to supply some of the excess load. If the excess load appears upon the other side the conditions will be reversed. Either motor may act as a generator or motor, as conditions require.

The field rheostat is used to equalize the voltage of the two machines and should be placed in the stronger field. Very often the coil on the starting box serves to unbalance the fields and must then be arranged on the opposite side from the field rheostat.

In old installations the capacity of compensators is sometimes overtaxed by the addition of too many lights or motors. In such a case an artificial balancing load is often added, as shown at L. The lamps there shown may be connected to either side of the system, as the case may require.

Storage batteries, as shown in Figure 128, can also be used for purposes of balancing as above.

CHAPTER XI

OPERATION OF ALTERNATORS

The operation of a single phase alternator working alone is not much different from that of a direct current machine. Such machines may be compound wound, as illustrated in Figure 53, in which case that part of the current which circulates around the fields must be made to circulate always in the same direction, as in direct current machines. This is accomplished by means of the rectifier shown in Figure 53. Each of the sections of the rectifier are in connection with one of the collector rings and subject to changes in the direction of current in the same way as the collector rings. The rectifier is mounted upon the same shaft as the armature and moves with it in such a manner that whenever the current in the armature falls to zero the change of brushes from one section to the other occurs.

So long as the brushes are set in this position there is no sparking, but since there is considerable variation in the inductance of an alternating circuit the current is not always at 0 when it should be and, therefore, at times there is very severe sparking. Compound wound alternators are, therefore, not much used at present.

Some generators have two brushes in each lead of the rectifier. The trailing brush is set permanently and the leading brushes alone are changed with changes in the inductance of the load. All alternators

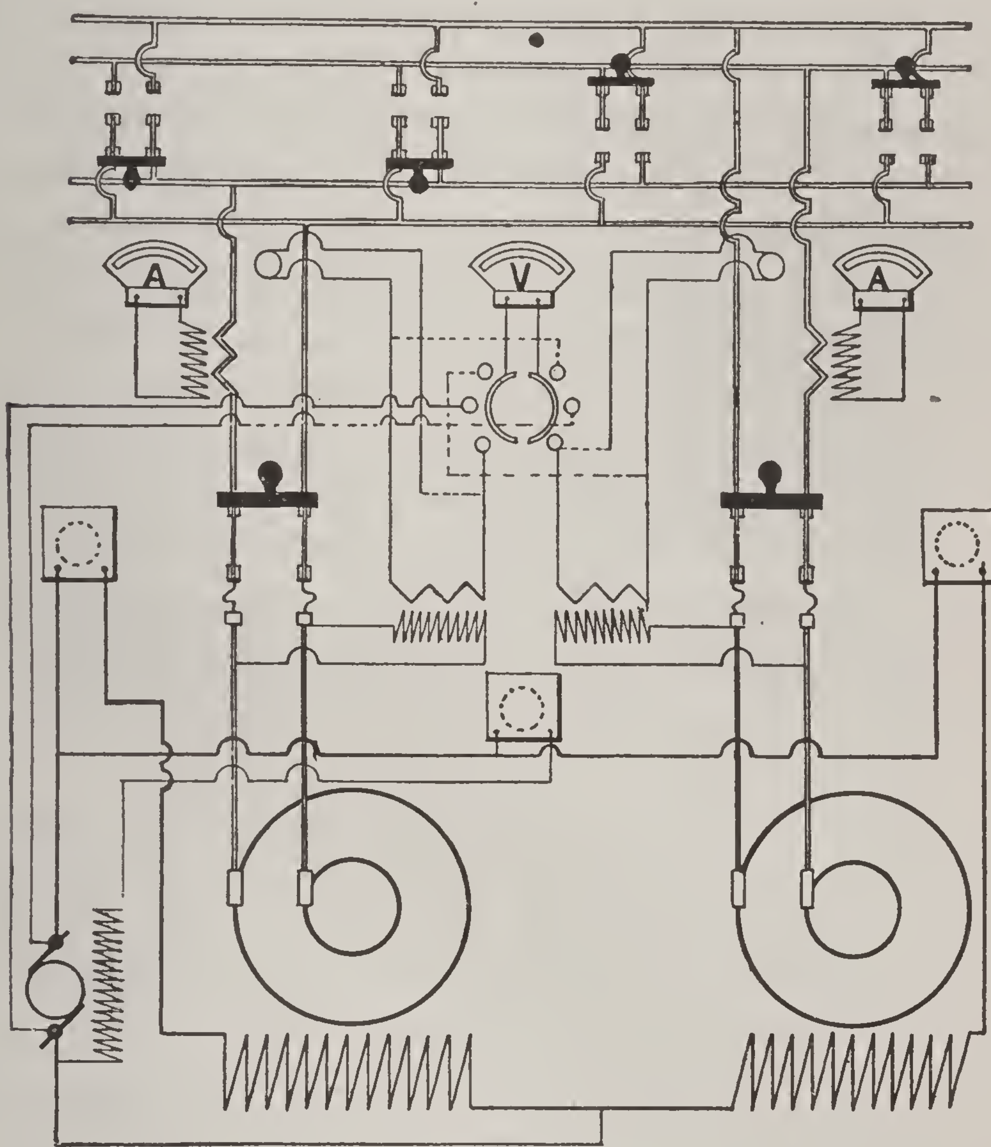


Figure 83

are separately excited by means of a direct current dynamo and the first step, therefore, is to bring this exciter in running order. This is done in the same manner as with shunt dynamos previously explained.

Figure 83 shows two alternators connected to a

switchboard. The instruments are operated through suitable transformers, as is customary with high tension installations. Both machines are excited by the same dynamo, but each, of course, has its own field rheostat, and there is a third rheostat for the exciter. The operation of alternators in parallel, though practical, is somewhat difficult, and requires close attention on the part of attendants; it is therefore often avoided, and the switchboard shown is divided so that each machine can take care of part of the load without being connected to the other. By means of the overthrow switches any or all of the lights or motors may be connected to either of the machines. Transfer from one machine to the other may be made at any time without shutting down motors, provided, of course, the machine will not be overloaded thereby. If a very large motor, however, happens to be heavily loaded, it is best to shut it down and start it again after transferring.

In order to operate alternators in parallel, several precautions are necessary:

They must all run very closely at the same speed and the fluctuations in speed must vary in about the same degree and occur at the same time.

The E.M.F.s of the machines must be the same and they must be synchronized, i. e., they must pass through their respective maximum and minimum values at the same time. In order to get a clearer understanding of this refer to Figure 84. This figure shows two series of sine curves, which represent the currents of two machines. Both machines are working at the same E.M.F., but the one represented by the lower part

of the figure moves through eight cycles in the same length of time that the upper passes through seven. Beginning at the left the polarities of the dynamos are exactly opposite at the same time and there can, therefore, be no cross currents between them. Gradually the lower machine gains on the other until at the center of the figure one is positive and the other negative; at this point they are working in series instead of parallel, which is equivalent to a dead short circuit, so that all of the current circulates between the two machines and none of it goes out to the line. Continuing still farther at the right, they are again opposed to each other and working in parallel. It will be seen at once that two dynamos working in this manner cannot be coupled together without causing serious damage to both of them.

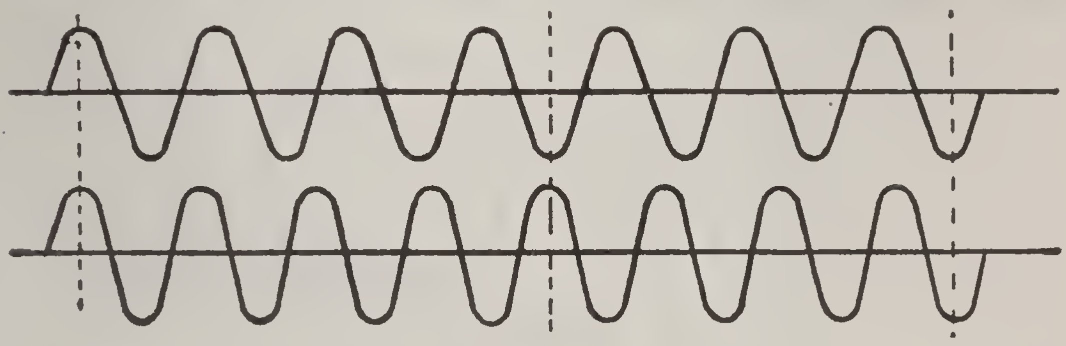


Figure 84

In order to attain smooth and economical operation it is necessary that both machines keep together in speed at all times. If they are nearly so a slight current from the leading machine passing into the lagging one will help operate it and thus speed it up to keep pace with the other, but the less of such a current is necessary the better it is.

If such dynamos are operated from a common shaft it will be well to leave the belt of one of them slack so that the other can easily force it into synchronism. If they are operated by separate steam engines, the piston strokes of the engines should be synchronized. Referring to Figure 85, it can be seen that the engine receives nearly if not all of its power during the time that the crank pin is moving from 1 to 2 and from 3 to 4. During the time it is moving from 2 to 3 and 4 to 1 the steam is not only shut off, but some of it actually forms a cushion, which checks the motion. While these differences in speed caused in this way are not

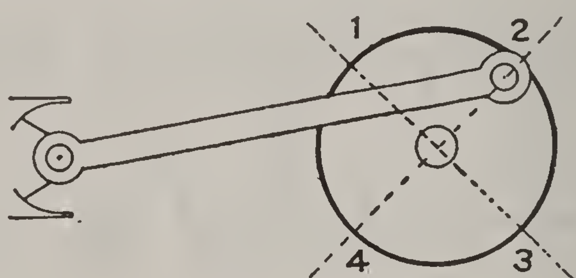


Figure 85

perceptible to the eye, they are sufficiently great to cause very damaging cross currents to circulate between the dynamos.

There are some specially designed machines that do not require such close synchronization. Such machines are provided for operation in connection with gas engines. These engines often miss fire and drop the whole load for an instant, and it is no unusual thing to see the ammeters of such machines swinging from zero to the maximum.

In operating two alternators in parallel we begin by starting the first one, bringing it up to its proper voltage and speed and giving it about the load it

should carry. The other machine is next started and if it has not been tried before the first step is to test it for polarity, i. e., to see that similar poles of both machines connect to the same bus bars. The simplest method of doing this is shown in Figure 86, but this method must not be used with high tension work. If the polarity of the second machine is right, the lamps shown at L will all be bright and dark at the same time. If the machines should accidentally be in phase with each other, the lamps would be dark continually,

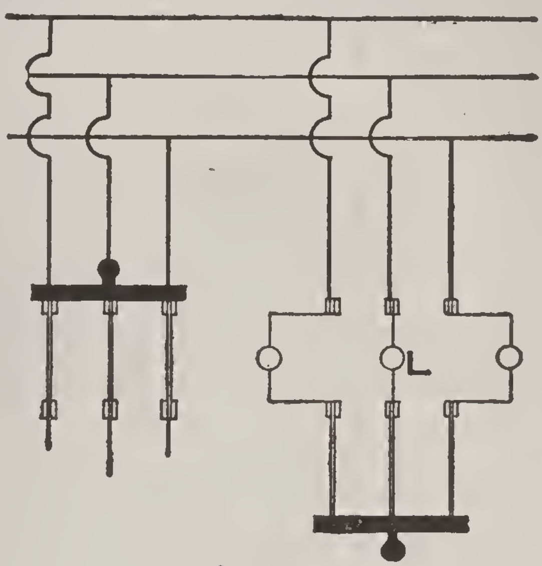


Figure 86

but as this will probably never occur they will alternate between light and dark with more or less rapidity. If the lamps do not go up and down together, two of the leading wires from one of the machines must be changed until the lamps are operating together. Lamps used for this purpose must be capable of standing double the pressure of the system since the only time at which they will be bright is when the dynamos are coupled in series and at double voltage.

The polarity of the machines being in order, the next step is to bring them in synchronism. There are different methods of doing this, illustrated further on, so we shall give here one of the simplest methods, but one that is suitable for low voltages only. In Figure 87 one synchronizing lamp is provided for each dy-

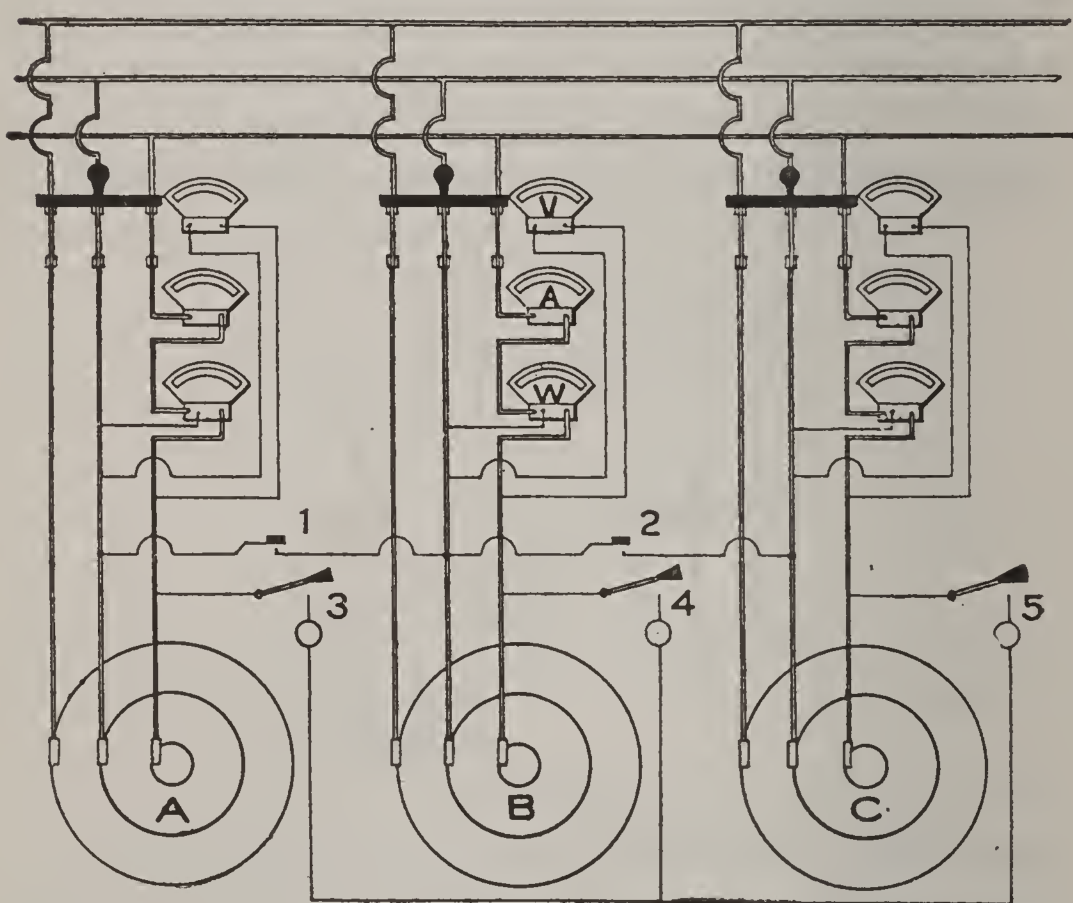


Figure 87

namo, as shown. Suppose dynamo A to be running and that B is to be put in parallel with it. By closing the switches 1, 3 and 4, circuit is established through the two lamps and similar phase wires on the two machines and the lamps are connected to two similar wires. If the voltage of the two wires is the same and the maxima occur at the same time the lamps will be

dark and remain dark as long as the above condition prevails. But if one machine moves faster than the other, the same effect described before will be noticed on the lamps, viz: they will alternately light up and become dark. The nearer synchronism the two machines are the longer will be the periods of light and darkness. The new machine must now be regulated so as to bring it nearly to the same speed as the other, and at about the middle of one of the dark periods when they are of several seconds duration the switch may be thrown in and the dynamos allowed to work together.

It is not possible to divide the load between alternators by simply raising the voltage of one machine, as is done with direct current machines. In order to increase the current in one of the machines, the engine driving it must be made to do more work by giving it more steam, and a governor by which this can be done must be provided. Giving an engine more steam will cause it to speed up a little and thus create a slight cross current, which will help drive the other. If a very great load is to be shifted from one dynamo to another, it is best to speed up the dynamo as above and also to increase its voltage a little, and to perform both operations by small steps, a little increase in power, then a little increase in pressure, a little more power and a little more pressure, etc.

The currents circulating between two machines differing only in voltage are wattless and do nothing but heat the wires. In order to get the best distribution of load an indicating watt meter should be placed in the circuit of each machine and the watts of both of

them kept in proportion to the capacity of the machines. If such instruments are not at hand there must be an ammeter for each, and there should be a main line ammeter which measure the total current. If the sum of the machine currents is greater than the total line current, it is an indication of cross currents flowing between the machines. The dynamos must be sc adjusted that the sum of the dynamo currents becomes a minimum. When this is the case the cross currents are at their lowest value.

The rheostats of the different machines should be worked in such a manner that the voltage of the line is not affected more than absolutely necessary while distributing the load. This is done by working the sevral rheostats a little at a time; increasing one and decreasing another, thus trying out how best the load can be distributed without changing the voltage of the system. If there is a power factor meter for each machine, they should be made to read alike and this will indicate that the machines are working properly.

Some of the larger systems using alternating currents have two systems of bus bars that may be used in parallel or may be separated when occasion requires. When such are to be connected in parallel there are two groups of generators to be synchronized instead of single machines. This is generally accomplished by taking one or more generators out of service of the group which is running at the higher speed. This forces the total load on one engine less and thereby causes the whole group to run slower. When thus the two groups are in synchronism they may be coupled together.

Rotary converters are operated in the same manner as alternators. They must be first brought up to speed by means of some outside source of power, usually an induction motor, or from the direct current side, and then synchronized. If there are several such converters, the load must be divided between them by strengthening the field of the one that is to take more current.

By proper manipulation of the excitation the power factor of a given load can also be materially affected and occasional attempts to improve it will do no harm.

The power factor of a line indicates the ratio of the true power transmitted to the apparent power. To find the real power being delivered by an alternating current system, we must multiply the product of the volts and amperes by the power factor. The power factor of a system supplying incandescent lights only is ordinarily about .95 while with induction motors it is often as low as .70, especially if the motors are not used at proper load. Whenever the power factor is low, the system is operating at poor efficiency.

Long distance transmission lines are frequently designed for very great losses at full load. In such a case the voltage will be too low for satisfactory operation when the full load is being used and if, to overcome this, the pressure of the dynamo is raised it will be too high on circuits that are not heavily loaded. In order to obtain satisfactory operation under such circumstances some means must be provided whereby the pressure on different branch circuits can be regulated without changing the voltage of the dynamo.

The Stillwell regulator is the best known of these.

and is typical of all the others. Each regulator must be provided with two windings and is really a transformer, the primary circuit of which is connected across the mains and the secondary in series with the main current. In Figure 88 S is a double throw switch, by means of which the primary coils Y can be connected so as to raise or lower the voltage of the line. By means of the handle C as much of the secondary winding can be inserted into the main circuit as may be found necessary, and this may assist or oppose the main line voltage. The inductance L is provided to

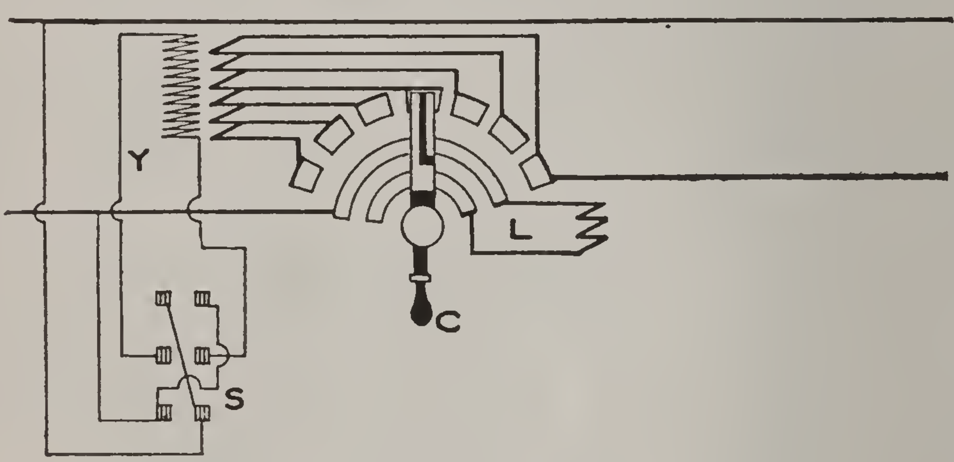


Figure 88

prevent serious short circuiting of any of the secondary coils while the contacts of C are moved from one segment to another. It will be seen that C is split and that therefore during the time that it bridges two segments the currents induced in the coil between them must pass through L.

SYNCHRONIZERS

To connect a direct current generator in parallel with a generator already running the voltage of the

generator to be connected must be adjusted to correspond with the voltage of the generator which is running, or with the bus bars to which the generator is connected. When their voltages are alike the generator circuit may be closed.

When alternating current generators are connected in parallel, the geneartor to be connected must not only correspond in voltage, but it must also be in "synchronism" with the other generators feeding into the bus bars. Two alternating currents are in synchronism when their phases coincide, or when all changes in their E.M.F.'s exactly correspond. Both must reach a positive maximum value at exactly the same time. If two generators were connected together when their E.M.F.'s were 180° out of phase, or when the E.M.F. of one machine was at a positive and the other at a negative maximum for instance, a direct short circuit would occur. The conditions would then be very similar to those existing where a direct current generator with its polarity reversed was thrown in parallel with another machine. The positive of one machine would then be connected directly to the negative of the remaining machine and a severe short circuit would result.

Where the currents of two alternators are only slightly out of phase, the incoming machine will be brought into step with those already running, but a considerable strain will be imposed on all the machines and considerable current will flow between them. In order to ascertain when two alternators are in synchronism, synchronizers are used. The simplest form of synchronizer consists of two incandescent lamps con-

nected in series between the machines as shown by broken lines in Figure 89.

If the brushes bearing on the same collector rings are to be connected together, or to the same bus bar, it is evident that when the two machines are in phase, or synchronism, the two brushes will at any moment be at the same potential and of the same polarity. The E.M.F.'s of the two generators being directly opposed the lamps connected between them will not burn. This

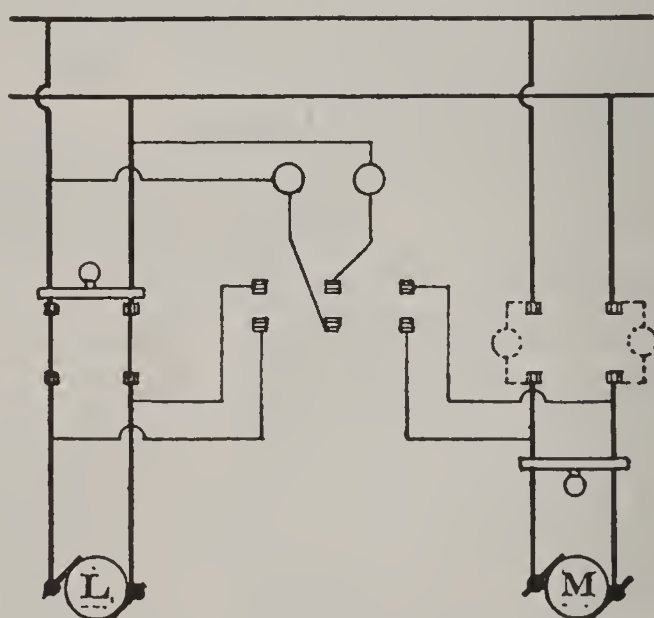


Figure 89

is called synchronizing "dark," due to the fact that the lamps remain dark when the generators are in step. Suppose the currents in the two generators were 180° out of phase. When one of the collecting rings of machine L is positive, the corresponding ring of machine M is negative and the two machines are then generating in series. The two lamps will, therefore, burn at full candle power, the combined E.M.F.'s of the two generators being now impressed on the lamps. Two lamps of the same voltage as the generators or one

lamp of a voltage suitable for the combined voltage of the two generators may be used.

If the two generators continued to run under the same conditions as those just described, and did not change in speed, the two lamps would continue to burn at full candle power; but if one of the machines runs at a slightly slower speed, the positive maximum values of the E.M.F. of this machine would occur just a little later than that of the other, finally falling back to a point where the two generators come again in synchronism, at which point the lamps would be dark. As long as the generators are varying in speed, the lamps will alternately light up and go out, this change occurring more rapidly as the difference in their speed increases and gradually dying out as they approach uniformity. As they approach synchronism the intervals between the time of light and dark will grow longer and when a point is reached where the lamps stay dark for a considerable time, the main switch may be thrown in and the machines run together.

In synchronizing alternators, it is safer to close the main switches just before the point of synchronism is reached than after, as some little time is required to throw in the main switches.

In order that the lamps may be used with either machine and without leaving them continually in connection with either of the machines they may be arranged as shown in the center of the figure. The overthrow switch must be thrown towards the incoming machine.

The use of synchronizing lamps, as shown in Figure

89, is limited to low voltages. Transformers may be connected in the generator circuit, as shown in Figure 90. This arrangement allows the use of ordinary voltage lamps, irrespective of the voltage of the generators. If the transformers are so connected that their secondaries oppose each other when the generators are in step the darkness of the lamp will indicate the point of synchronism. If either one of the primaries or secondaries of the transformers are reversed the transformer secondaries will be in series and assist each other and the point of synchronism will be indi-

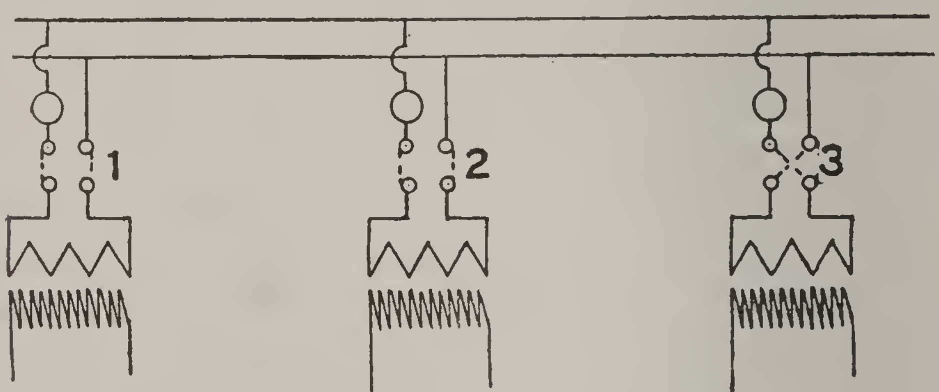


Figure 90

cated by the lamp burning at full brightness. This is known as synchronizinz "bright." Either method may be used and both have their advantages and disadvantages.

If both of the plugs used make the same connection as indicated at 1 and 2, the lamps will be dark at synchronism; if one of the plugs reverses connections, as at 3, the lamps will be bright at synchronism. When the machines are running together the synchronizing bus is entirely disconnected. When synchronizing bright, the eye becomes more or less fatigued by constantly watching the lamp and the point of full bright-

ness may be misjudged. On the other hand an incandescent lamp requires considerable voltage before the filament becomes visible and darkness does not necessarily denote that no current is flowing, or the filament may be broken during the time of synchronizing. To overcome these objections mechanical syn-

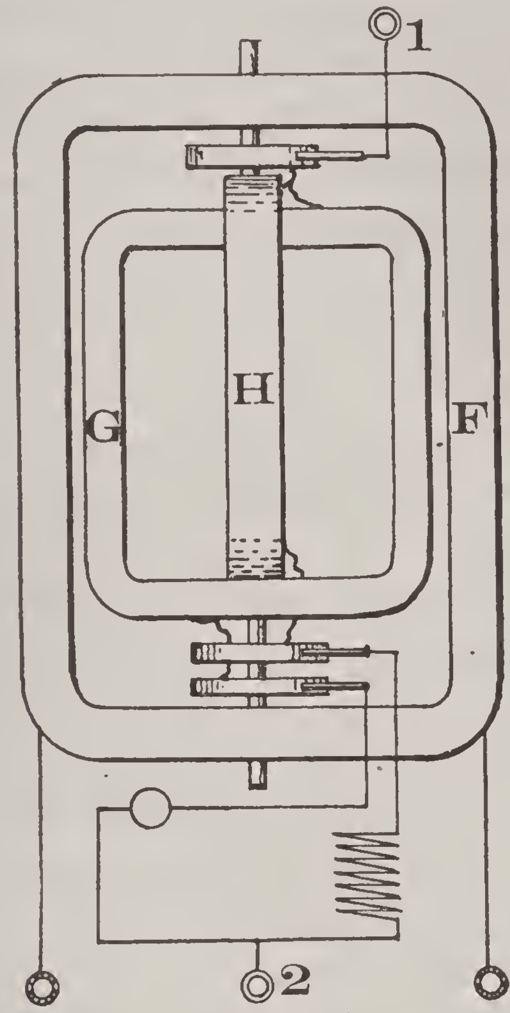


Figure 91

chronizers have been devised and are now generally used, which will not only accurately indicate the exact point of synchrony but will also show which machine is running too fast or too slow.

The Lincoln synchroscope is a device designed for this purpose. The principle of its operation may be

understood by reference to Figure 91, where F represents a stationary field supplied with current through the two lower binding posts on the instrument to one of the generators. The two coils G and H at right angles to each other, are mounted on a shaft and are free to revolve about their common axis. The windings of the movable coils are brought to a common junction and carried to a slip ring mounted on the shaft, connection being made from this point to a binding post at the top of the instrument. The remaining ends of the coils are carried to two other slip rings. Connected in series with one of the coils is a non-inductive resistance (incandescent lamp) and in series with the other coil an inductive resistance or choke coil. From these resistances the connections are brought to a common point and carried to the remaining binding post.

Connection is made from the binding posts 1 and 2 to one of the machines to be synchronized and from the other binding posts to the remaining machine. When an alternating current is passed through the movable coils, there will be a phase difference of 90° between the current in coil G and that in coil H, and a rotating magnetic field will result. This rotating field acting in conjunction with the rapidly reversing field of coil F will cause the movable coil to revolve. A pointer attached to the shaft of this coil indicates the direction and extent of the movement.

As long as the two generators vary in speed the pointer will continue to revolve, turning at a greater rate with a greater difference in speed and slower as the generators approach synchronism. Should the

machine which was running faster, decrease in speed and run slower than the other machine, the pointer would revolve at a slower rate and finally run in the reverse direction. When the machines are running at exactly the same speed, the pointer will come to rest. If the machines are in phase the pointer will come to rest in an upright position; if out of phase, the position of the pointer will indicate the difference in phase between the currents in the two machines.

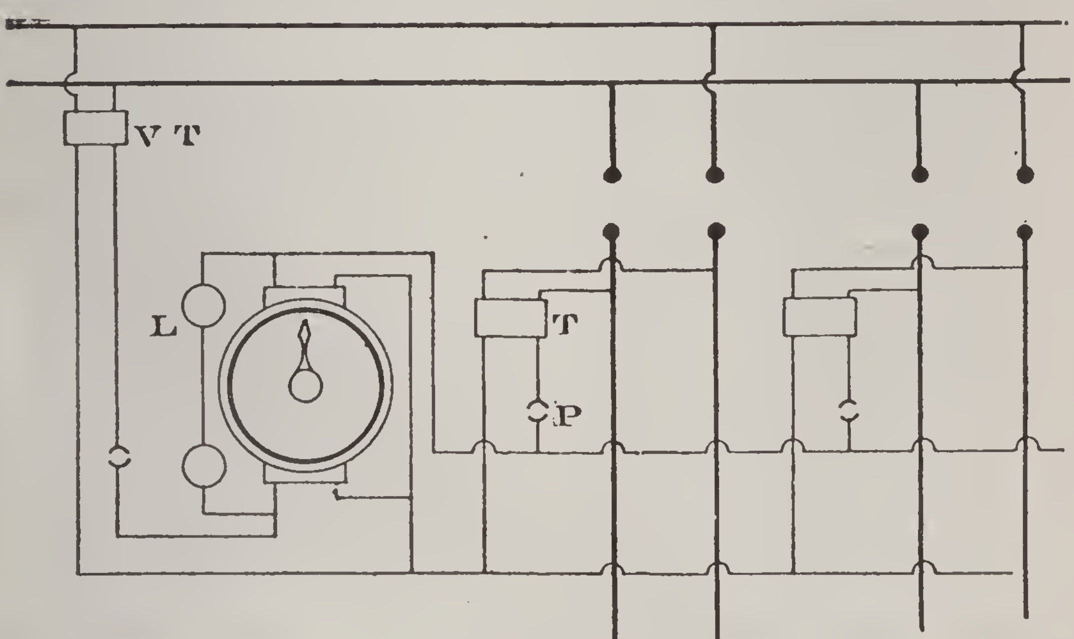


Figure 92

Synchronizing lamps are often used in connection with synchronizers. If the difference in speed between two generators is great, the instruments do not always indicate right, and for this reason the synchronization is started with the lamps and finished off with the instrument. In connecting up a synchroscope it should always be checked with lamps to see that it indicates right. If it does not, some of the wires must be changed until it does.

Figure 92 shows the switchboard connections of the Westinghouse synchroscope arranged for high potential. V T are the voltage transformers, one for each machine, P the plug receptacles and L the synchronizing lamps.

The power factor meter is similar in principle to the synchroscope and the switchboard connections for two phase are shown in Figure 93, and for three phase in Figure 94. If necessary a voltage transformer is cut into the circuit, as indicated by dotted lines. Three

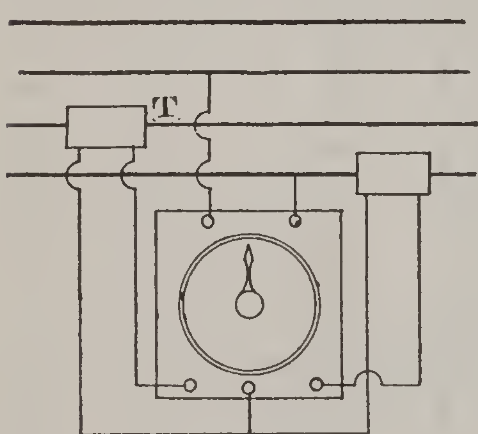


Figure 93

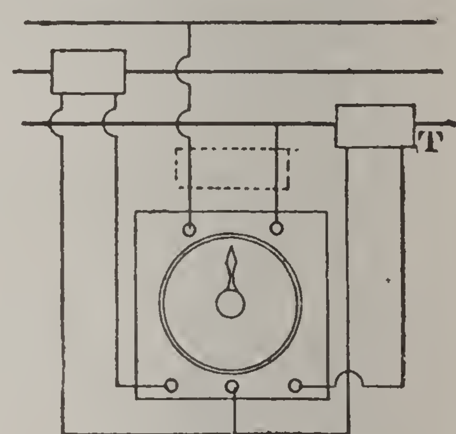


Figure 94

lamps cross connected between the three phases as shown in Figure 95 can also be used for synchronizing in connection with three phase circuits.

Let the two halves of the figure at the right and left each represent a dynamo, both of which are to be operated together. If both are running at the same speed they will be in synchronism and whatever relation as to brilliancy between the different lamps may exist at any moment will exist at all times, i. e., the lights will work in unison either up or down. If, however, one of the machines is moving faster there

will be a steady change in all of the lights. To get a clearer view of this let the machine at the right be moving twice as fast as the one at the left. The E.M.F.s of the two machines will then at any time be represented by the length of the line measured from A, B, C, either up or down until it intersects the sine curves.

To find the brilliancy of any of the lamps A B C we must note the differenec of potential between the

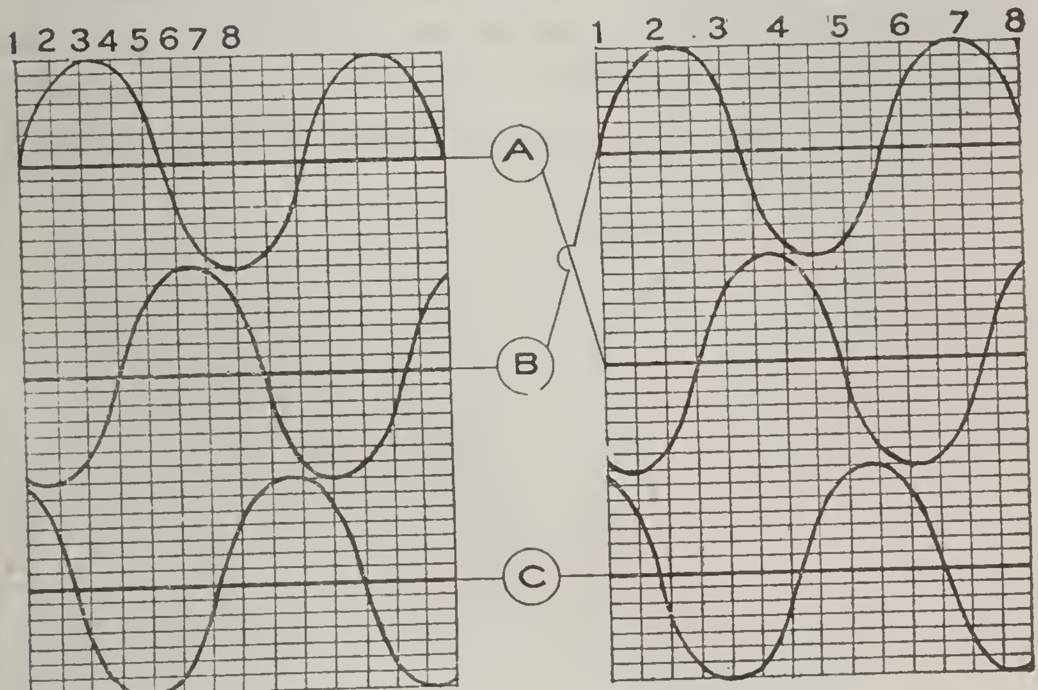


Figure 95

phases to which it is connected. If both E.M.F.s are above the horizontal line they must be subtracted, the lesser from the greater, if one is above and the other below the values must be added, since they represent opposite polarities. Following this out we obtain the table below in which the numbers stand for relative brilliancy, 0 representing darkness and 14 the highest obtainable voltage which is double that of one dynamo.

The numbers 1, 1, 2, 2, etc., indicate the advance in speed of one machine over the other, that at the right moving twice as fast as the other.

TABLE A

	1-1	2-2	3-3	4-4	5-5	6-6	7-7	8-8
A	6	11	2	0	5	4	2	13
B	6	14	9	6	11	3	0	3
C	0	6	4	5	13	11	3	11

With conditions as above the lamps will light up in the order A, B, C. If the machine at the left moves faster than the other the lamps will light up in the order C, B, A and thus give an indication as to whether the incoming machine is running too fast or too slow.

CHAPTER XII

MOTOR OPERATION

We have already seen that the ordinary direct current motor requires some resistance in the circuit at starting to prevent an excessive rush of current during the time the armature is developing the necessary counter E.M.F.

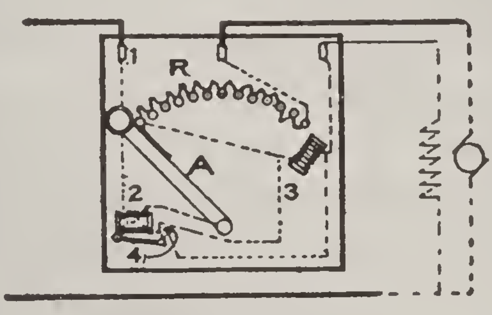


Figure 96

One of the best rheostats for this purpose used in connection with shunt or compound motors is illustrated in Figure 96. This rheostat is equipped with "overload" and "no voltage" releases. Both of these are necessary to protect the motor properly but it is possible to operate motors without them as the ordinary fuse, if of proper size, will take care of the motor. An overload will cause excessive current to pass through the armature and a drop in voltage will do the same thing especially if it is sufficient to cause

the motor to come to rest, in which case the armature becomes a short circuit and will rapidly burn out.

Referring to the diagram, current enters at 1 and passes through magnet 2 and the arm A of the rheostat. Here the circuit is open until the arm is moved to the right; when the arm touches the first point of R current begins to flow through all of the resistance and the armature and at the same time through the fields. It is important that the conections be so made that the field is fully excited before the armature receives much current as the current will flow through the armature much more rapidly than through the fields. It will be seen that the field current passes through magnet 3 and when the arm is finally brought to the last point this magnet engages an iron armature on the arm A and thus holds it at that point as long as current flows through the magnet. Should the voltage of the circuit drop off considerably the magnet will be unable to hold the arm and a strong spring attached to it will force it back to the off position. Should the motor be overloaded the armature of magnet 2 will be drawn up and close the circuit at 4; this will shunt the current around magnet 3 and cause it to release the arm which will then fly back. If desired, push buttons or switches can be attached to this shunt circuit in the same manner at different places, so that the motor can be stopped from any of these points.

Attention is called to the manner of connecting up this rheostat; it will be noticed that the field circuit is never entirely opened. This is an important feature as it prevents much of the destructive sparking

which always occurs when a circuit containing electromagnets is opened. It also saves the insulation of the motor from many very severe strains as a very high E.M.F. is developed for an instant when the field circuit is broken. With this connection this is avoided and the field discharge passes through the armature which acts as generator through this circuit until it comes to rest. If the switch on a motor provided with a rheostat as shown is suddenly opened the arm of the rheostat will not fly back at once but will be held in place by the current generated by the armature for a few moments until it comes nearly to rest.

The rheostat should always be located so that the action of the motor can be observed from this place; if belting, etc., connected to the motor can be seen from the rheostat it will answer the purpose.

The first step in starting a motor is to close the main switch; next move the arm of the starting box slowly and note whether the armature begins to move. If it does not do so it is not safe to continue movement of the arm, but instead it should be returned and the cause of the trouble located. (See Motor Troubles.)

Ordinarily not more than 30 seconds should be consumed in moving the arm from starting position to position of rest. If more time is taken the rheostat coils are likely to burn out. This of course depends very much upon the load the motor may be carrying when starting. If the arm is moved over too fast the armature is likely to burn out. This also depends greatly upon the load it may be carrying at the time. During the time of starting and immdeiately afterward the condition of the brushes should be noted and

they should be adjusted to point of least sparking. Good modern motors should not spark at all. Motors equipped with starting boxes like the above will generally take care of themselves if for any reason the current should fail. If the starting box is not automatic the switch of the motor should be opened at once in case the current fails; a sudden coming on of the current would either blow fuses or burn out the armature. Motors with such starters should also be disconnected from the service before the generators are shut down at noon or evening. This may be done either by the attendant at the motor or by the man in charge of the switchboard. In all larger, well managed installations it is customary to have certain men detailed to stop and start all motors at the proper time.

Series motors, such as are used on street railways, cranes, etc., unless specially wound or used in connection with a very steady load require constant attention and cannot be operated unless an attendant is always at hand.

ALTERNATING CURRENT MOTORS

Alternating current motors fall into three general classes: Single phase induction motors; polyphase induction motors; synchronous motors. The single phase induction motor requires some artificial means of starting, as illustrated in Figure 63. The direction of rotation can be varied by reversing the connections of either one of the two windings.

The smaller of these motors require no starting boxes. At starting they draw a very heavy current,

usually from 5 to 6 times the running current, but this soon ceases.

With the larger motors up to 5 H.P. the switching arrangement shown in Figure 65 may be used. This switch is shown three phase but may be used equally well with single phase. The switch is thrown to the up position and held there until the motor has gained considerable speed and the heaviest rush of current is over; it is then thrown downward and the motor continues to run but now under protection of the fuses. This throwing over of the switch must be quickly done so that the motor will not lose much speed in the interval during which it is without current.

If an induction motor is overloaded it will often come completely to rest and burn out.

The motor most commonly used for power purposes is the 3 phase motor. Two phase systems are not much used. This motor is self starting and requires no help in this respect. But like the single phase motor the currents required at starting are very much greater than the running current. It is therefore customary to use the same starting devices as with single phase motors, but as this type of motor is used in much larger units than the single phase better starting devices are furnished.

Figure 69 shows a diagram of an auto starter used with 3 phase motor. So long as the switch is in the position shown the current must pass through the reactances 1, 2, 3, and these prevent the heavy rush of current which would take place otherwise. After the motor has attained nearly its running speed the

switch is thrown up and the motor receives the full line pressure.

It is always best to arrange such motors so they can be started without load.

With larger sizes of induction motors the rotor is often wound. In such cases a resistance may be placed in the motor circuit and operated as with direct current motors. The resistance may be fully cut out when the motor attains full speed (See Figure 68.)

Three phase motors may be reversed in direction by changing the relative position of any two wires leading into the motor.

With all induction motors the efficiency is quite low unless the rotor is made with a very small air gap between it and the stator. A very small amount of wear will therefore be likely to bring both in touch and ruin the motor. For this reason great care in the application of belts must be used; too tight a belt will soon wear the journals and allow the rotor to come in contact with the stator.

A three phase motor will not start unless all of the wires are delivering current, but it will continue to run if one or two of the phases are out of circuit. Under these conditions, however, it will draw very heavy currents and very likely burn out.

Polyphase synchronous motors, if there is no other way, may be started by allowing current to flow in the armature while the field circuit is open. This method gives rise to much trouble and is not to be recommended. Such motors should be brought up to speed and started like alternators running in parallel. (See Synchronizers and Operation of Alternators.)

CHAPTER XIII

TRANSFORMERS

The losses of energy in an electric circuit are proportional to the current flowing. The power transmitted is proportional to the product of the current and pressure-amperes and volts. Bearing these two facts in mind, we can easily see that to reduce losses to a minimum we should work with a minimum current, but as we decrease the current we must increase the voltage in the same ratio. To transmit a given amount of power, if we divide the current by 2, we must multiply the volts by 2.

High electrical pressure, it is well known, is quite dangerous, not only to human life, but there is also considerable fire hazard with it and it is furthermore impracticable to use it in many places where, for instance, insulation is difficult. This fact again makes it desirable to avoid the use of high pressures where it is likely that inexperienced humanity may come in contact with it.

In the electric transformer we have the means of using electrical pressure at a low potential, if necessary, inside of buildings, increasing that pressure to a great extent out of doors and reducing it again to a safe potential when we enter the premises where power is to be used.

Since we can raise the pressure to a great extent on that part of the line which is pretty well out of reach of most people, we need but a correspondingly small current and can, therefore, get along with correspondingly small wires.

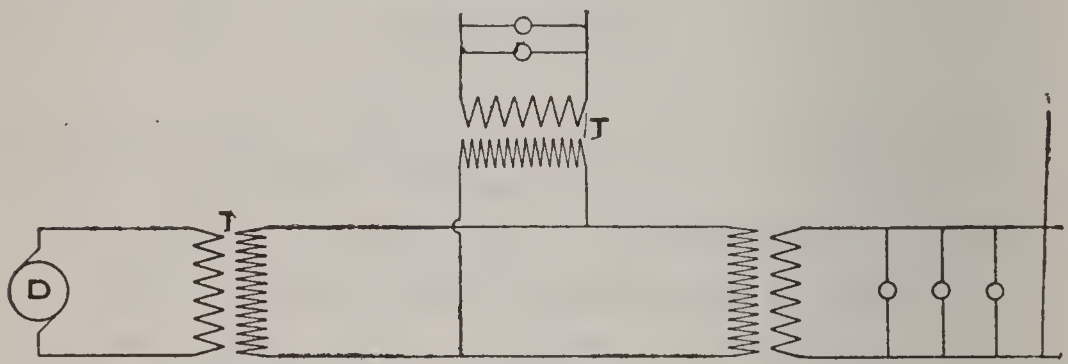


Figure 97

An illustration of such an installation is diagrammatically shown in Figure 97. The transformer T nearest the dynamo is known as a "step up" and the other as a "step down" transformer. A step up

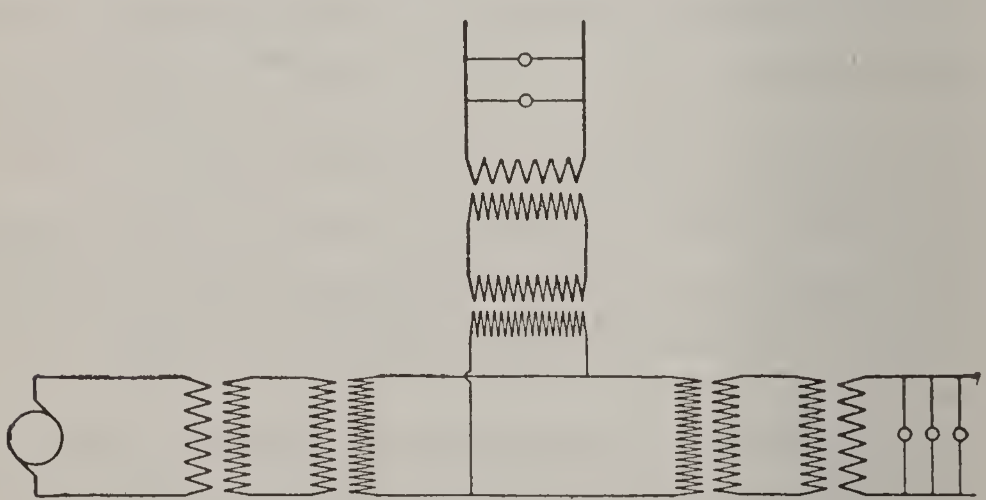


Figure 98

transformer is not always used, very often the full line potential, is generate direct by the dynamo. On the other hand, in many cases a double transformation is required as illustrated in Figure 98. This only as

a safeguard, however, as it has no operating advantages; it merely reduces the liability of breakdown in the insulation.

A complete comprehension of the transformer requires a knowledge of the phenomena of electrical induction and inductance and without this knowledge one cannot intelligently operate or test transformers. The term "electrical induction" describes the inducing of one current by another. We are already somewhat familiar with the phenomenon of lines of force cutting wires, but it will do no harm to touch upon this subject again.

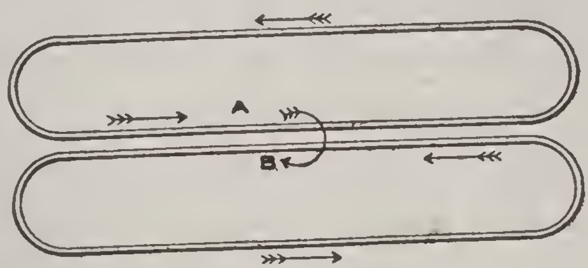


Figure 99

Referring to Figure 99, if a current is started in one of the closed circuits, A, for instance, it will set up lines of force encircling the wire as indicated by the arrow, B. These lines of force we know require power to create and oppose the current which is creating them. So long, however, as their only chance of action is on the same conductor in which the current which gives rise to them flows, their only effect is to retard or check the current flow as long as they are increasing in number. After they have attained a steady value, they no longer retard the current, in fact have no further effect on it until they begin to decrease in number again. If, however, these lines of

force are in position to "cut," i. e., to encircle another closed conductor, they at once give rise to currents in it and these currents since they are created by a force which opposed the original current or force must, of course, be in opposition to it. Thus it is that whenever two closed conductors are laid side by side and a current is set up in either of them, another current opposing the first will be set up in the other circuit. Thus the first current is said to induce the other and is spoken of as an inducting or primary current, while the other is known as the induced, or secondary current. The phenomenon above referred to is that of electrical induction and every change in current strength and direction in one such conductor will be followed by a corresponding change in tne other.

We have seen how an electric current induces another current in a neighboring conductor if that conductor is part of a separate coil. Similar induction also takes place in wires belonging to the same coil, as these are also cut by the same lines of force and as this opposes the original current, it gives rise to what is known as the counter E.M.F. of self-induction, or self induction, or inductance.

We have now a clear view of these two phenomena; that the primary coil tends to induce currents in the secondary coil and also opposes itself. We have also seen in previous chapters that both of these effects are largely increased if the wires are wound upon an iron core having high magnetic conductivity. With every good transformer there is a magnetic circuit of very high conductivity, so that the self induction of the primary circuit is very great. In fact, it is the aim

of all builders to make it so great that very little current will flow while only the primary coil is connected.

Now let us examine the effect of the secondary coil. We know that the primary coil induces currents in it which flow in opposition to those in the primary. Furthermore, it is evident these currents must react upon the primary in just the reverse direction that the primary currents react upon themselves, in other words, they tend to lessen the self induction of the primary coil and bring about a greater current flow in it. The secondary coil also, of course, reacts upon itself, but this reaction is again balanced by the greater action of the primary. Thus the whole current flow in a well designed transformer is governed by the secondary coil. If it is an open circuit, no current flows; if one light is turned on, there is some flow; if more are turned on, the current is in proportion, all of course within the range of the carrying capacity of the wires. This interaction of the two currents is called "mutual induction" and it is this interaction which makes the transformer so useful and efficient.

In practice the electric transformer consists of an iron core upon which two separate coils of wire are wound.

These two coils must be insulated from each other, but should otherwise be as close together as proper regard for safety will permit. One of the coils of wire is usually subject to much higher pressure than the other and there is always danger of the insulation between them breaking down. Many fires and some loss of life have been caused by this.

In Figure 100 there is shown a diagrammatic illustration of a transformer having a ratio of 10 to 2; by this is meant that the number of turns of wire in one coil is 5 times as great as in the other; with this ratio the voltage in the coil having the most turns will be 5 times as great as in the other, while in the other the current will be 5 times as great as in the first. In both coils the power will be the same, if they are properly designed; if we neglect the losses due to heating hysteresis, etc., which, however, in large well-designed transformers, should not be over two or

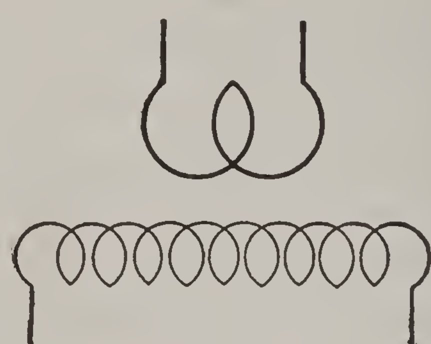


Figure 100

three per cent and if they are operated on full load even less.

In order to see more clearly that the power in both coils is the same, we must bear in mind that the secondary coil can deliver no more power than it receives from the primary and (supposing a transformer of 100 per cent efficiency) the primary coil must be of such self induction that no current whatever will flow as long as the secondary coil is on open circuit. Hence the primary can deliver only enough power to provide what the secondary is taking and the power in the coils must be always the same.

The losses in the transformer are due: First, to the ohmic resistance of the coils; second, to inefficiency of the magnetic circuit provided by the iron core; third, to eddy or foucault currents generated in the iron core and also in the copper wires themselves (this is very small), and fourth, to hysteresis.

As transformers grow old, they are very apt to lose in efficiency, although some makers have recently produced iron which it is claimed does not deteriorate with age.

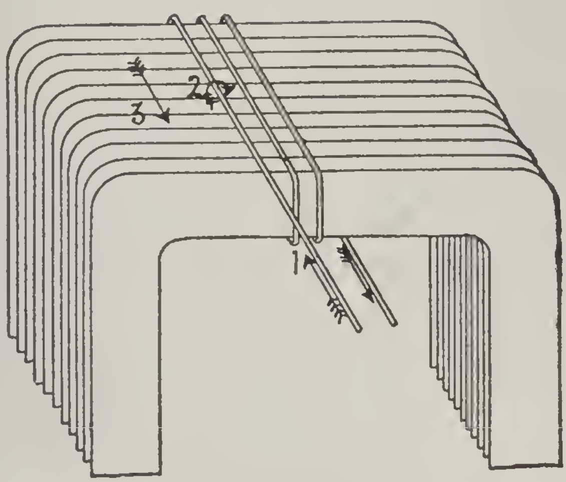


Figure 101

The losses due to ohmic resistance can be reduced by using larger wire of higher conductivity. The losses due to foucault currents are kept at a minimum by "laminating" the iron core of the transformer. Since foucault currents are induced by lines of force which act at right angles to the inducing current, they must flow in the same general directions as the currents which produce them, hence, to introduce as much resistance as possible into their circuit (which is the iron core) it is built up of thin washers insulated from each other, sometimes by thin paper, often by merely

the oxidization on the sides of the plates. The relative position of wire and plates is shown in Figure 101; arrow 1 shows direction of inducing current, arrow 2, direction of lines of force and arrow 3, direction foucault currents would take if the insulation between the laminations did not prevent them.

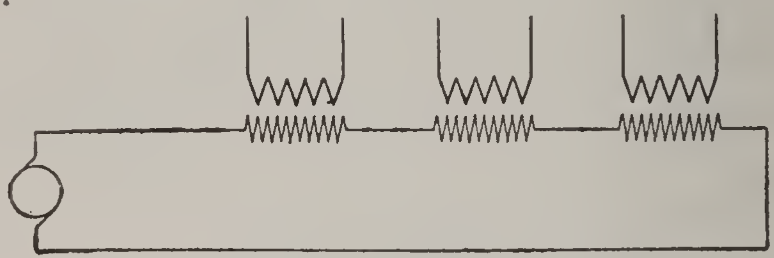


Figure 102

Transformers are connected in series sometimes, as shown in Figure 102. As a rule transformers connected this way are small, each supplying only a few lights.

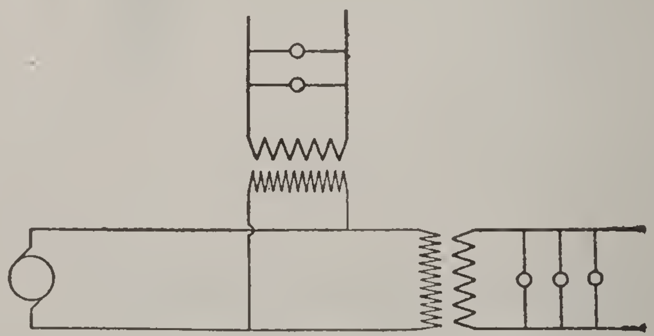


Figure 103

The majority of transformers are connected in parallel, as illustrated in Figures 103, 104 and 105.

Figure 103 is the simplest and requires no other testing than to determine which is the primary wire. This is usually easily determined by simply noting the size of the two pairs of wires which project from the transformer, the smaller being the primary. Should

these wires be identical in size, the resistances of the two coils should be measured. This can be done with a wheatstone bridge or with a voltmeter, the volt-

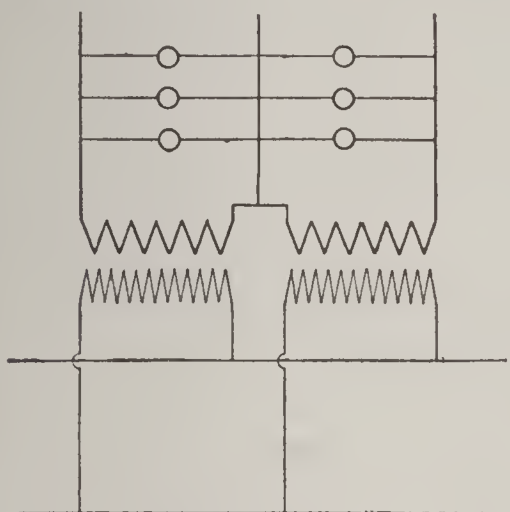


Figure 104

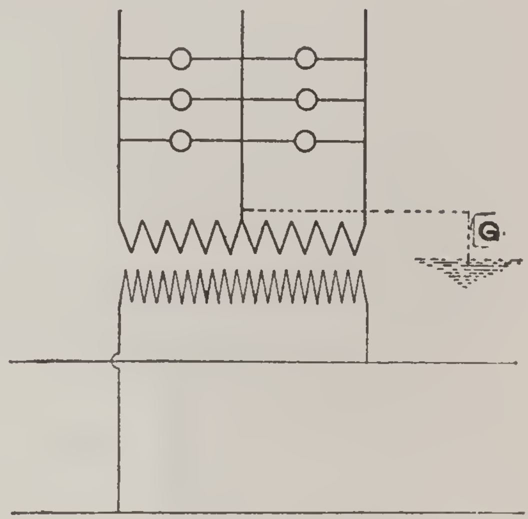


Figure 105

meter test being made as shown in diagram, Figure 106. Use a low potential circuit and direct cur-

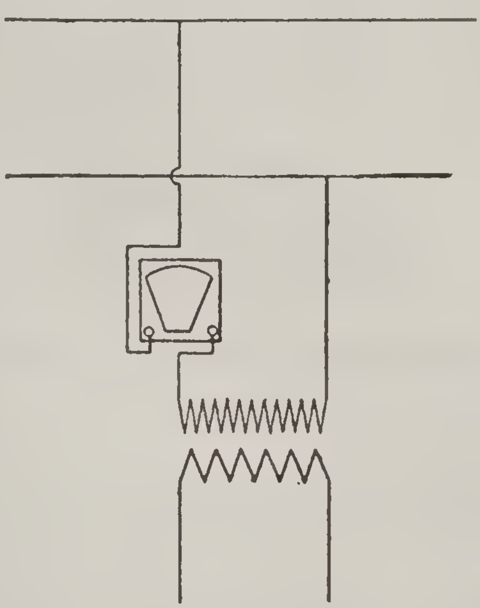


Figure 106

rent if possible and allow no one to come in contact with the ends of the coils as a very high potential may be generated in one of them.

The coil having the higher resistance will show the lowest reading on voltmeter and may be set down as the primary in case of a step down transformer and secondary in case of a step up transformer.

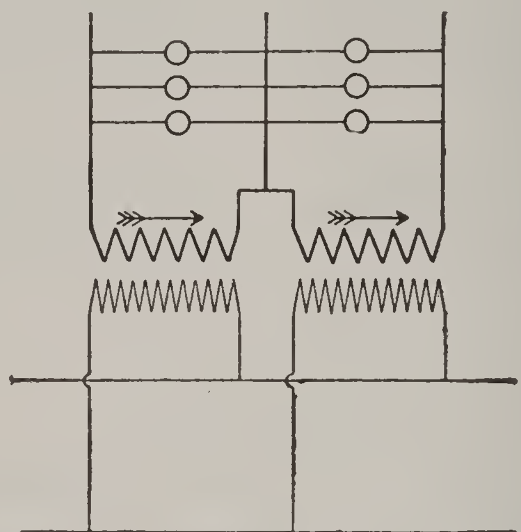


Figure 107

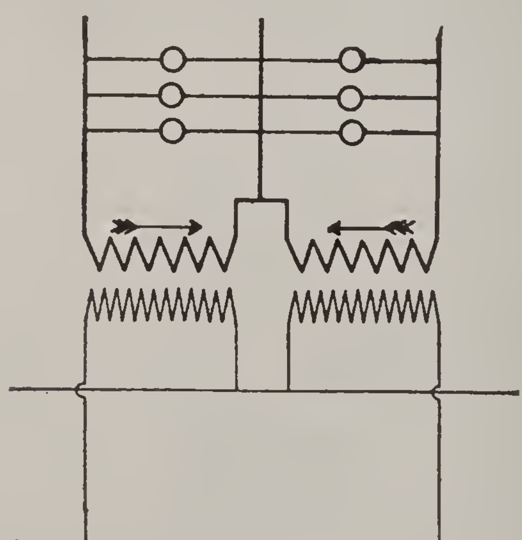


Figure 108

Transformers are often connected so that their secondaries may operate on the 3-wire system. Figures 107 and 108 show the right and wrong connections. Both methods will operate the lights, but with the wrong method the neutral or middle wire will be called

upon to carry double current and the loss in the wires will probably be excessive. With the right method, both transformers will use only as much current as one would use, but they will have double voltage, 2 lights being in series. This method makes possible a great saving in wire. One can easily determine whether such a bank of transformers is connected right or wrong by connecting two lamps across the two outside wires without connecting to the neutral. If the lamps

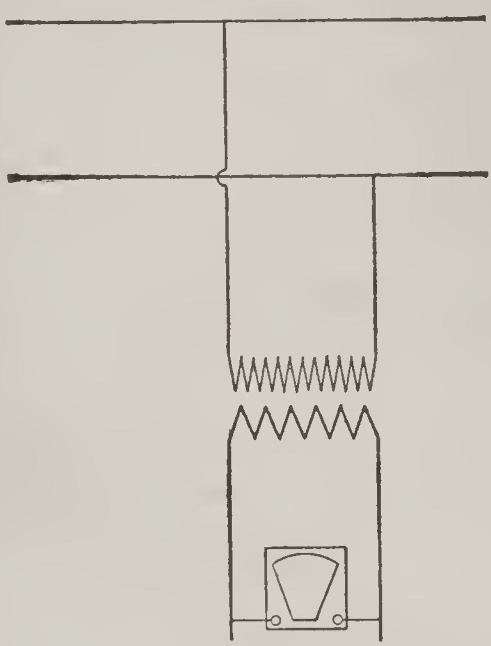


Figure 109

burn properly the transformers are O K.; if they are connected wrong the lights will not burn at all.

When transformers are banked either in parallel or in series it is necessary that their polarity be known. With transformers of the same make, it is safe enough to assume that all are of the same polarity and to connect them accordingly. If, however, transformers of different make are to be run together, they should be tested and marked beforehand. To do this make con-

nections to some direct current as shown in Figure 109. A direct current applied to a transformer will cause one impulse to be given to the voltmeter or galvanometer shown in the secondary. On each transformer mark that wire of the primary which gives a certain deflection on the voltmeter and in banking these transformers, see that these marked wires all connect to the same primary wire for parallel working. For this test a voltmeter whose deflections depend upon the direction of current must be chosen.

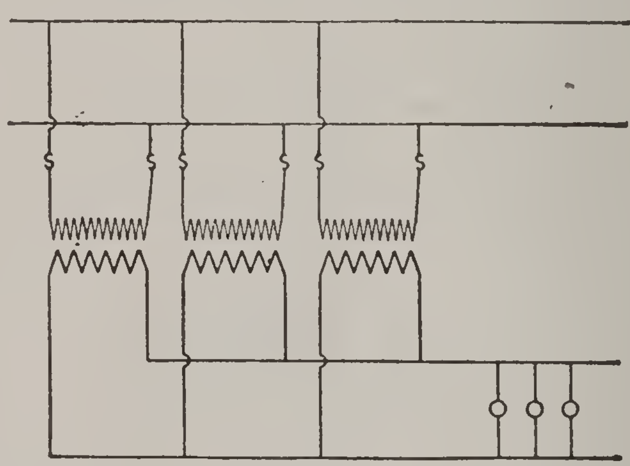


Figure 110

In Figure 110 another system of banking transformers is shown that often leads to trouble. If the primary fuse in one transformer "blows," it is evident that current from the other transformers will circulate in the secondary and thus add the transformer to the load in lights they have to carry, thus shortly causing other fuses to blow. Small transformers are far less efficient than large ones and this connection should not be used when it can be avoided.

Transformers to operate with a given voltage and frequency must be designed for this. If a higher

frequency is employed than the transformer is designed for, its self-induction will be too great to permit current flow. If the frequency is less than called for by the transformer, it will generate excessive volt-

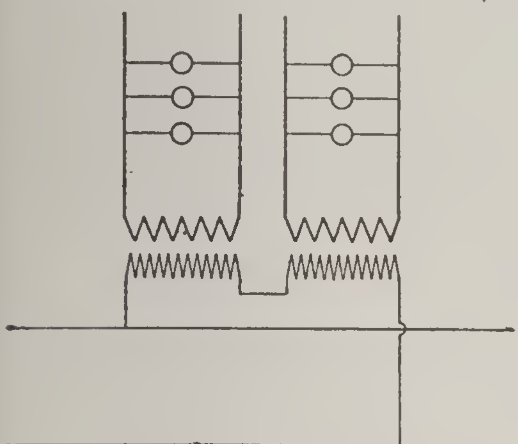


Figure 111

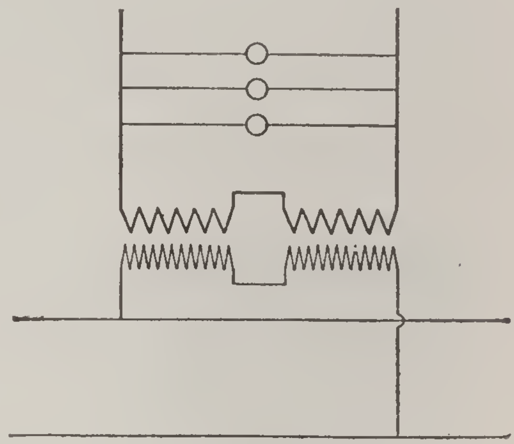


Figure 112

age and overheat the transformer unless fuses are blown.

Two transformers of the proper frequency, but only one-half the voltage of the circuit may be operated in series in either of the ways shown in Figures 111 and 112.

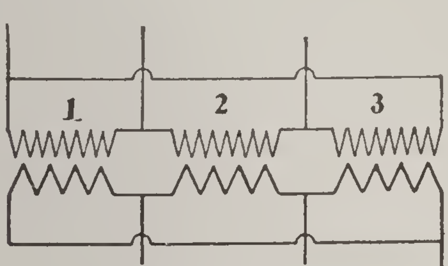


Figure 113

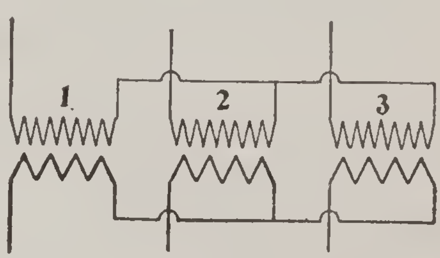


Figure 114

Figures 113 and 114 shows methods of connecting three-phase transformers. Figure 113 shows what is termed the delta connection and Figure 114 the Y or star connection. The delta connection has the advantage that the burning out of one transformer does

not seriously affect the operation of the other two, and even when two transformers fail the third will still operate on one phase. This is not the case with the star connection, one transformer failing seriously hampers the whole group.

Figure 115 is drawn to illustrate the voltage or current relations existing between star and delta connected transformers. S represents the star, and D the

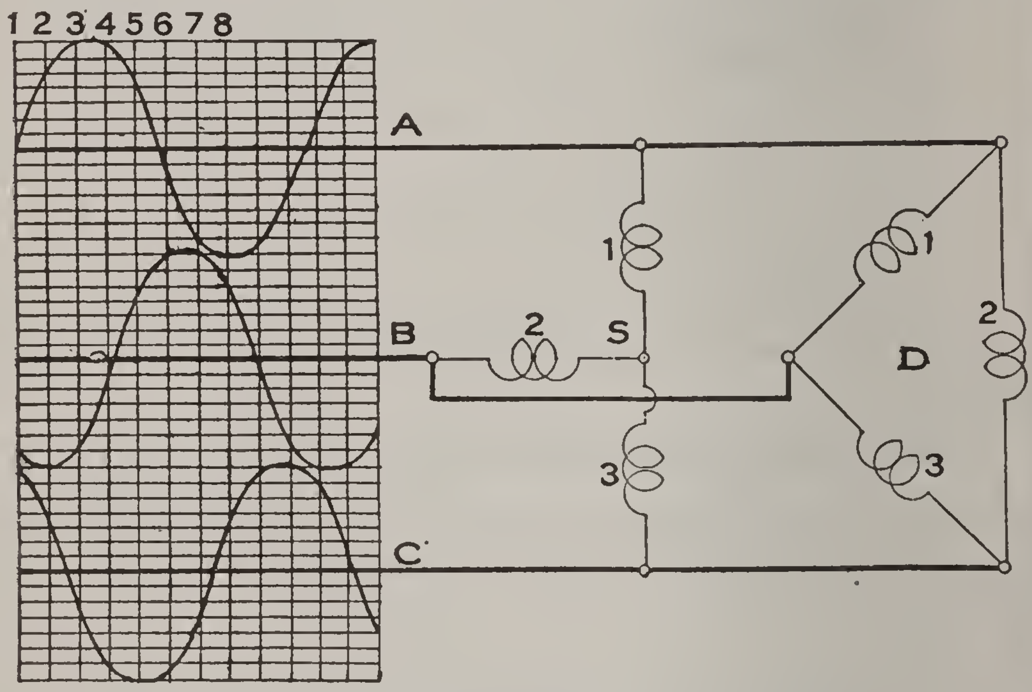


Figure 115

delta connection. Suppose the current be as shown by the curves under 1 at the left. At this instant phase A is at zero, and B is negative and equal to C positive. This leaves S1 without current for an instant and S2 and 3 in series taking the voltage of two phases. Between 3 and 4 A has risen to its maximum positive and B and C are negative and equal. The total current now passes through S1 and divides equally on the return through S2 and 3. At 5 A and

B are both positive and C is at a maximum negative, thus taking all of the current coming through S1 and 2 through S3. The above relation of the current in the different phases will hold for all intermediate positions and it can be seen that at no time is any one transformer coil subject to more than the current of one phase.

If we take up the delta connection in the same way we shall notice that at 1 coil D3 is subject singly to the pressure of two phases. There being no pressure at A, at this point current is also passing through D1 and 2 in series.

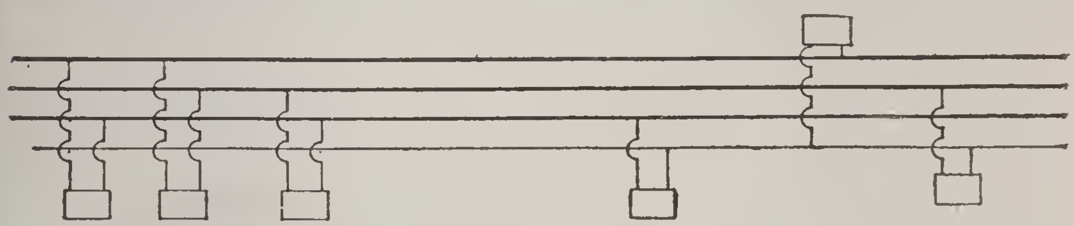


Figure 116

A complete investigation of this shows that with a given circuit for star connection the individual transformers are subject to only .58 of the voltage between the phases necessary, or for transformers to be used with the delta connection. If the same transformers used for star are connected delta, the current required for the delivery of a certain amount of power will be 1.73 times as great for the delta connection as for the star. While many transformers are so built as to be serviceable on either connection, it will not be safe to assume that all of them are and the operator should first inform himself on this point.

Figure 116 shows the methods of connecting up distributed transformers on three-phase circuits. The

three heavy lines denote the three-phase wires which carry the main current and the light line denotes a fourth wire used for balancing. This wire may be run all the way from the generators or may run only between the different transformers This wire is necessary when a number of transformers located some distance apart are to be connected star, but is not needed for delta connection. It is also not generally used where a bank of transformers are feeding a lot of motors or a big installation of lights. Whether the transformers are connected star or delta, or whether they are located close together or long distance

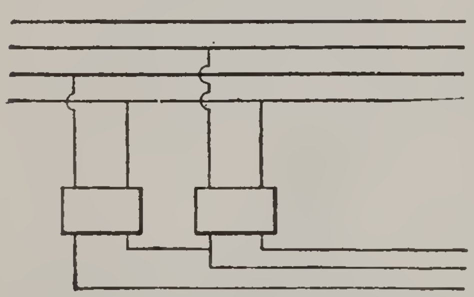


Figure 117

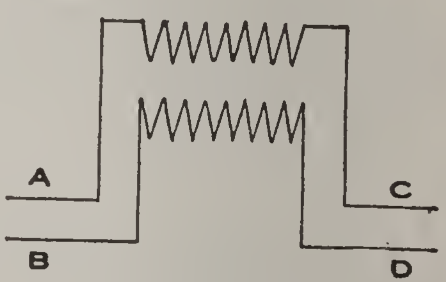


Figure 118

apart, it is always important to arrange so that the load may be as evenly as possible divided between the different phases.

In some instances, to save the cost of one transformer, three-phase transformers are connected as shown in Figure 117. Many transformers are wound so they can be used with different voltages and current. The manner in which this is effected is illustrated in Figure 118. If the ends A B and C D are joined the transformer-windings are fitted for but half the voltage but double the current as could be used if C were joined to B. This latter connection places windings

in series, while the former places them in parallel. In connecting two such coils in series care must be taken that current passes through both in the proper direction, if the connection should be made A C D B one-half of the transformer would oppose the other.

As it often happens that the insulation between the primary and secondary wires gives way and thus great danger to life and property results, it is advisable to ground transformers, as illustrated in Figure 105, the ground wire C being connected to some neutral point on transformer. The shells of all transformers should be grounded.

The principal losses in a transformer are the core losses, due to inefficiency of magnetic circuit, and the copper losses due to the ohmic resistance of the copper.

The efficiency of a transformer can be determined by measuring the power supplied to the primary by a watt-meter and dividing the power obtained from the secondary by it.

The core losses can be determined by measuring the current flowing in the primary while the secondary is open and noting the percentage of this current to the maximum current.

The copper losses are found by short circuiting the secondary winding and applying voltage enough to the primary to cause the full load current in the secondary. The greater the copper resistance, the more power must be supplied to the primaries. This power must also be measured with a wattmeter. Volt and ammeter measurements cannot be used with alternat-

ing currents. This method is due to Dr. Sumpner, and connections are shown in Figure 119.

Every transformer before being connected should be tested for insulation between the two coils and each coil for insulation from the shell, as well as for continuity. These tests can all be made with a wheatstone bridge.

As high potential is nearly always used in connection with transformers, great care is necessary in

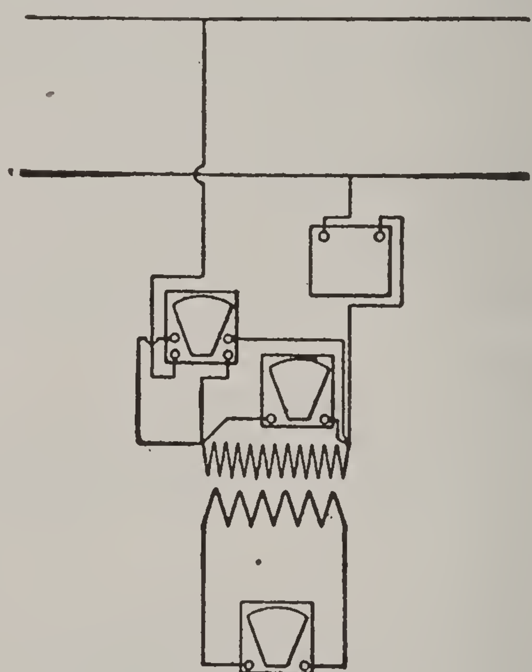


Figure 119

handling them. The following rules should be carefully observed:

Do not handle more than one wire at a time, and touch it only with one hand at a time.

Wear rubber gloves and do not let them be moist.

Keep yourself insulated from the ground and from all other wires.

Do not place fuses in circuit until all connections have been made.

Use enclosed fuses; a small rubber tube over the fuse wires is better than nothing.

If working on a line that is "dead," treat it as though alive. It may be "thrown in" at any moment.

Take no chances, protect yourself by short circuiting and grounding the line.

Be very careful not to part wires, keeping one end in each hand; you will cut yourself into the circuit.

With old transformers especially, and with all transformers that are not grounded, treat the secondaries as you would the primaries.

CHAPTER XIV

BATTERIES—PRIMARY BATTERIES

The term, battery, is applied to a number of cells grouped together either in series or in parallel. It should never be applied to a single cell. Batteries may be grouped according to any of the methods shown in

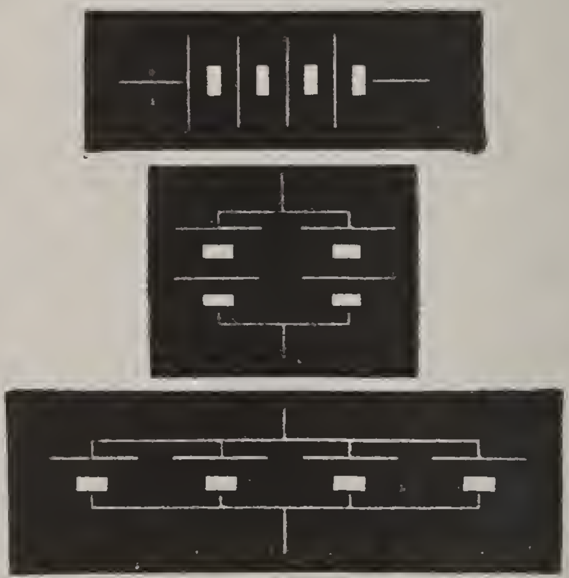


Figure 120

Figure 120. For all ordinary work, the method at the top is employed. The voltage of this arrangement is four times as great as that of a single cell.

If the same number of cells be grouped as in the center of the figure, the voltage will be but two times

that of one cell, but the current obtainable will be twice that of the above. With the arrangement at the bottom, the voltage will be equal to that of one cell, and the current obtainable four times as great as that from the first figure. The voltage of a number of cells in series is equal to the voltage of one cell multiplied by the number of cells.

The voltage obtainable from any cell is independent of its size or of the distance apart of the plates. In any given cell, however, the current obtainable is proportional to the size of the plates opposed to each other in the solution, and inversely as their distance apart. The distance apart of the plates affects the current only, as it increases the resistance.

The fall of potential when current is flowing is proportional to the product of the resistance of the battery or cell and the current in amperes. If the battery has a high internal resistance therefor, the drop in voltage will be quite great when much current is taken from it.

A battery is placed to the best advantage when the cells are so arranged that their resistance is nearest equal to that of the line through which they are working. If the resistance of the line or instruments is greater than that of the battery all of the cells should be placed in series; if the external resistance is less than that of the battery, the cells should be arranged in multiple until their resistance becomes as low as that of the line.

The resistance of a number of cells in series is equal to the resistance of one cell multiplied by the total number of cells.

The resistance of a number of cells in parallel is equal to the total resistance of one of the series groups divided by the number of sets in parallel.

Primary batteries are divided into two classes; one of these is suitable for continuous work only, and will rapidly deteriorate unless kept at work. The other will very quickly run down when kept in continuous use.

The best known of the continuous current type is the "gravity cell." In this cell the positive pole con-

Figure 121

sists of copper located at the bottom of the jar as shown in Figure 121, and the negative of zinc arranged at the top, as shown. Both of the elements are immersed in a solution of sulphate of copper commonly spoken of as "blue stone." This type is suitable only for such work as telegraphy, where very small currents are used. The internal resistance of this cell is very high.

The open circuit batteries are far more in use and exist in many forms and include nearly all of the different makes of dry batteries. Aside from dry bat-

teries, the most notable kind is the Leclanche. In this cell the positive pole is of carbon immersed in a solution of sal-ammoniac, and the negative pole is a piece of zinc immersed in the same liquid, but insulated from the carbon. This cell as well as the different kinds of dry batteries, are capable of delivering a strong current for a short time. If left in circuit, however, in a few minutes they will run down so that no current can be obtained. No matter, however, how badly such a cell may be run down in time it will often recuperate. These cells are universally used for bell and telephone work and consume no energy when not in use.

If the following directions are carefully observed little trouble will be experienced.

Leclanche and similar open circuit batteries.

Use no more salomoniac than will readily dissolve. Five or six ounces is the quantity required for ordinary cells.

Do not fill jar more than three-fourths full of water and keep it in a cool place to prevent evaporation.

See that water does not freeze.

Remove such zincs as become coated with crystals. They are impure and introduce very high resistance in the circuit.

Remove carbons and let them dry out occasionally.

Do not allow battery to be in use very long at one time.

Do not allow it to become short circuited.

If battery has been short circuited disconnect it and it will often pick up again.

CLOSED CIRCUIT BATTERY—GRAVITY CELL

Fill jar nearly full of water and throw in sufficient sulphate of copper (blue vitriol) to give a slight blue color to about half of the water. The blue part of the solution will be the heavier and will settle at the bottom. Enough should be provided so that the dividing line will be maintained about half way between the zinc and the copper.

To start the action of this battery it may be short circuited for a while; it must never be left on open circuit for any great length of time.

ACCUMULATORS OR STORAGE BATTERIES

Storage batteries are used in connection with isolated or central stations, to supply current when the dynamos are not running, as well as at the hours of heaviest load when perhaps the capacity of the dynamos may not be fully equal to the demands made upon them.

It must be borne in mind that it is not customary to provide dynamo capacity for all of the lights and power connected to the system, the assumption being that seldom more than 25 to 50 per cent of the connected load will be used at any one time. If a suitable storage battery is connected to the system, the dynamo capacity may be even less, for the battery can be charged during the slack hours when but very little current is being used for other purposes. Thus, if properly arranged, the dynamos and engines can be kept working at their full capacity and highest efficiency most of the time.

The plates of the cell are of lead (See Fig. 122) and there is always one more negative plate than there is of the positive. These plates are usually contained in glass or porcelain jars for the smaller sizes and for the larger portable batteries of hard rubber. The cells for very large permanent installations are often made up of heavy planking lined with lead.

The positive plate always contains the "formation which may be either mechanically applied, or

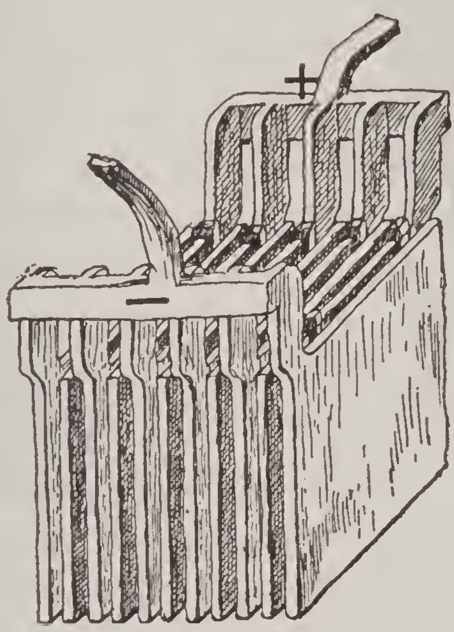


Figure 122

"formed" by the action of the charging current. Those batteries in which the active material is applied in the form of a paste are generally known as the Faure type, while those in which the active material is produced by charging and discharging are known as the Plante type.

The electrolyte used in connection with these batteries is always sulphuric acid diluted to a specific gravity, averaging about 1.20. The acid should be

pure and the water used should be distilled. The battery room should be well ventilated and all iron work should be covered with water proof paint. Wooden floors should not be used. Cement floors are best.

The cells should be well insulated and the specifications of the National Electrical Code should be followed in this respect.

The cells are connected with the positive pole of one to the negative of the other, just as an ordinary battery, and they may also be connected in multiple. Connection in multiple. however, has no advantage that can not much better be obtained by procuring larger cells and is, therefore, very seldom practiced.

The E.M.F. of a cell fully charged is about 2½ volts, and should not be carried much beyond this. When the cell is overcharged oxygen and hydrogen gas are given off. The E.M.F. should not be allowed to fall below 1.8 volts under any circumstances and the nearer at full charge the battery can be kept the better it is. On no account should any battery ever be left standing without charge, and the electrolyte should never be applied unless everything is in readiness for immediate charging.

The connections from one cell to another had better be soldered or welded so as to leave no chance for loose connection.

As the water evaporates, it must be from time to time replenished. This is best done with a hose which may lead the water into the bottom of the jar where otherwise the heaviest part of the solution will concentrate.

In handling water and acid, never pour water into acid; always pour the acid into the water. Much heat is generated when the two are mixed.

Every cell should be tested quite frequently with voltmeter and hydrometer. The best indications of the condition of a cell are obtained by hydrometer tests.

If the voltage of one cell is much lower than that of the others, the cause will often be found to be a short circuit of some kind in the cell.

To charge storage batteries it is necessary that the current pass into the battery in the opposite direction that current flows from the battery when in use.

In most cases it is necessary to charge the battery to a higher potential than that at which the dynamo operates. This cannot be done unless a "booster" of some kind is employed. A "booster" is merely a generator through which the total current passing into the battery flows and in which a certain addition to the voltage of the circuit is made.

Figure 123 shows the connections of a compound dynamo used to supply current to the bus bars, and also to charge a storage battery. In this figure B is a belt driven booster, through which all current passing from the dynamo into the battery must pass and in which the pressure can be raised the desired amount. This booster is provided with fields like an ordinary dynamo, and the field strength can be adjusted. To charge, the double throw switch S is thrown upward and current now passes from the plus pole of the dynamo to switch S, then along wire C to the main cells of the battery and through the battery

ammeter, the booster the other pole of switch S and the minus pole of the dynamo.

To discharge, the switch is thrown downward and current now passes in the reverse direction to the bus

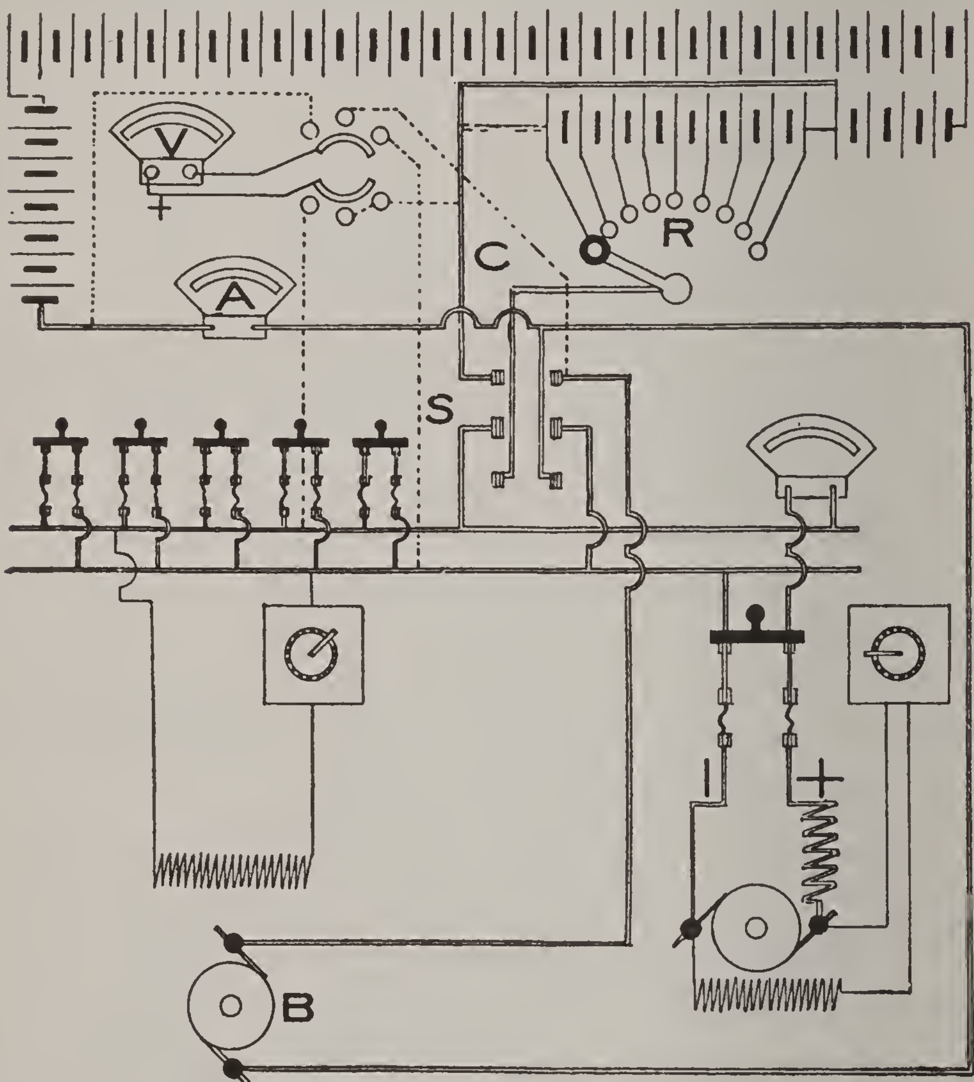


Figure 123

bars, leaving the booster out of circuit The discharge current, however, must pass through the cells connected at R. In the above case, these are simple lead plates known as counter E.M.F. cells and oppose the flow of current so that by their aid the rate of dis-

charge can be controlled. As the battery discharges and its E.M.F. falls more and more of the cells are cut out. Very often the method of regulation is by means of end cells which are charged at the same time as the battery. In such a case the connections must be as indicated by dotted lines and wire C, as the E.M.F. of the battery falls, more and more of the end cells are cut into the circuit and their E.M.F. added to that of the battery

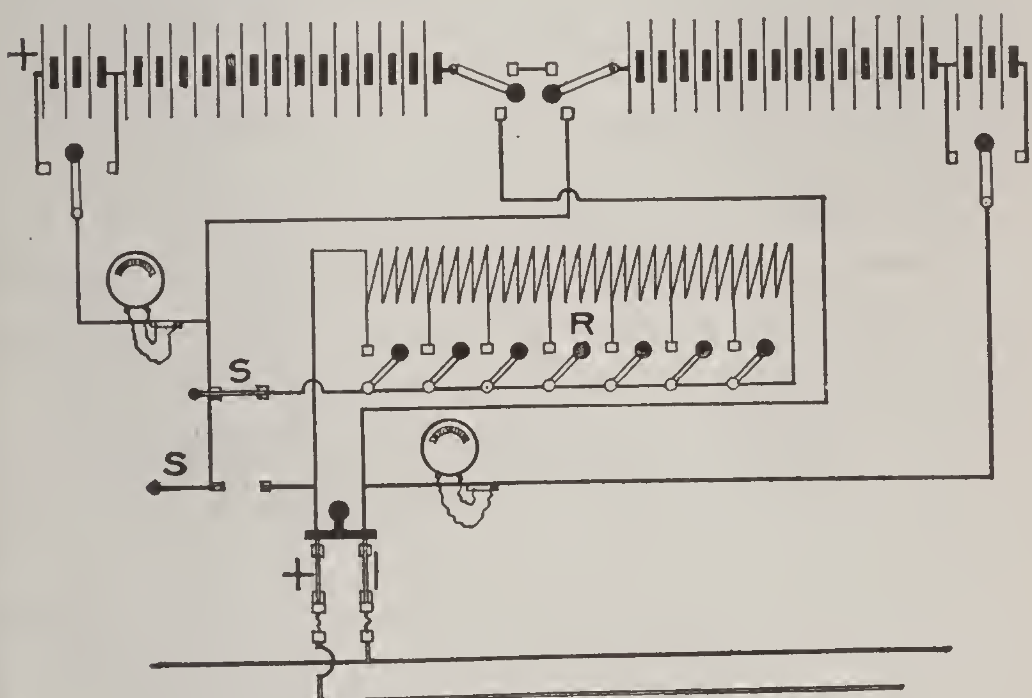


Figure 124

A method of arranging a storage battery so that it can be charged without the use of a booster is shown in Figure 124. This battery is arranged so it can be charged in parallel, and for this purpose is divided into two parts. When arranged for charge the two switches in the upper center are thrown downward and all of the end cells are cut into the circuit so they will be included in the charge. Current now passes

from the positive pole of the circuit through all of the resistance R, and the switch S to the two halves of the battery. As the counter E.M.F. of the battery develops resistance is cut out of the circuit by closing the switches connected to the resistance, beginning at the right, one at a time and as fast as it appears necessary. Closing the last of these switches at the left cuts out all resistance. Two ammeters are provided so the current in both sides can be watched.

Ordinarily this battery "floats" in the system and when arranged for work upper switch S is opened and lower switch S is closed. With this connection the battery will feed into the line whenever the pressure of the line falls below the normal and take current from the line when the pressure is normal or above. Double scale ammeters should be used. They will show whether the battery is receiving or sending current.

When storage batteries are to be charged from alternating current lines, the Cooper-Hewitt Mercury Rectifier may be used.

This mercury alternating current rectifier consists of a glass bulb fitted with four electrodes. Two of these are of graphite and two of mercury. The mercury electrode will not allow a negative current to pass through into the vapor in the bulb, but does not resist the flow of current from a positive source into itself, if that current has been once established. In order to start the flow of current from the positive electrodes P into the mercury electrode N it is necessary to establish a metallic circuit from P to N and when now this circuit is interrupted the current will continue to flow into the mercury from the vapor in the

bulb, so long as the current flow is not broken elsewhere. If for any reason the current flow ceases, it cannot again be started until the metallic circuit has again been established.

The operation of the rectifier can perhaps be best understood by reference to the Figure 125. In this

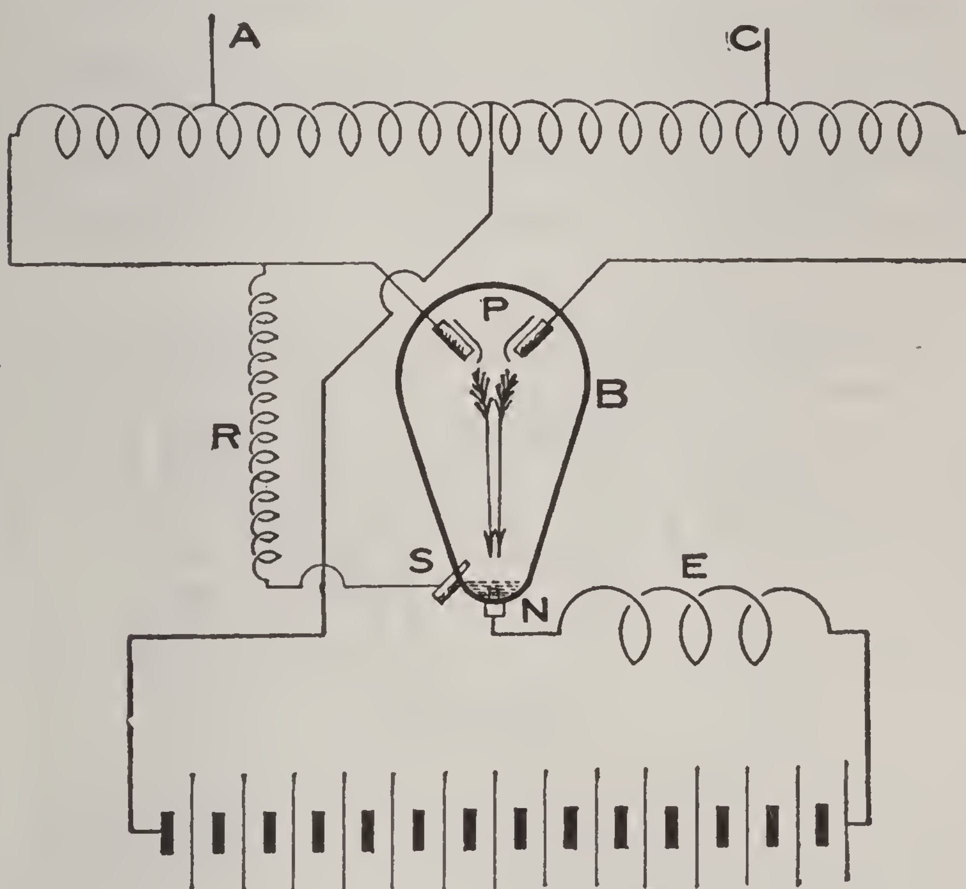


Figure 125

figure, A C is the source of the alternating current which is to be rectified for the purpose of charging the battery. The current passes from whichever side of A C may be positive to the positive electrodes P. So long as the bulb B remains in its upright position no current will flow from P into N. In order to start the flow it is necessary to tip the bulb a little to the

left so that the mercury in the bottom connects N and S. This starts current flow through the starting resistance R, and when the bulb is returned to the upright position the current continues; but not from S but from P. No current can pass from the mercury to the vapor, but there is no hindrance to current flow from the vapor to the mercury, provided it has been started. As the arc lamp maintains itself through the vapor formed by the arc, so the current there maintains itself when started through the vapor. Should, however, only for an instant the current flow be in-

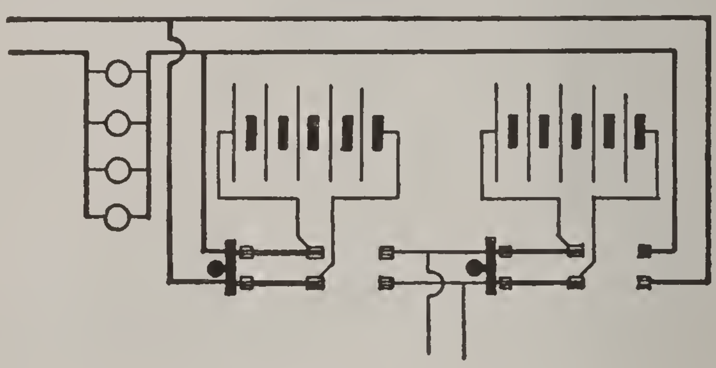


Figure 126

terrupted the bulb would have to be tilted again. It will be seen from the figure that each side of the A C has an electrode at P, and one of these is always positive and from whichever is positive the current flows into the mercury.

A reactance E is cut into the circuit which causes the current to continue after the E.M.F. has fallen to zero until the current at the other side has attained some value so that the flow is continuous.

Storage battery circuits are usually equipped with overload and underload circuit breakers, which pre-

vent charging at too great a rate and also a reversal of the battery current through the dynamo.

Small batteries for use in connection with bell or telephone work are best connected for charging as shown in Figure 126, one battery being connected to the work while the other is charging. This makes it impossible to bring the high voltage dynamo current in contact with the bell wiring which, as a rule, is not safe for such pressures. The rate of charge can be governed by using more or less lamps of different c. p. in the sockets indicated at the right of the figure.

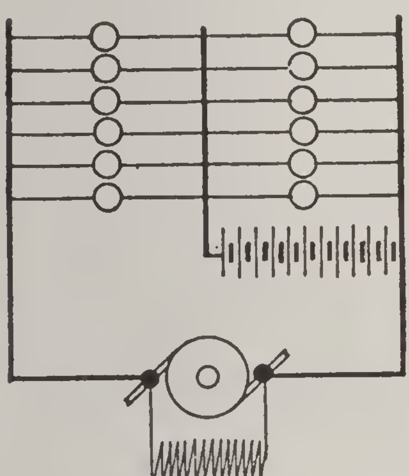


Figure 127

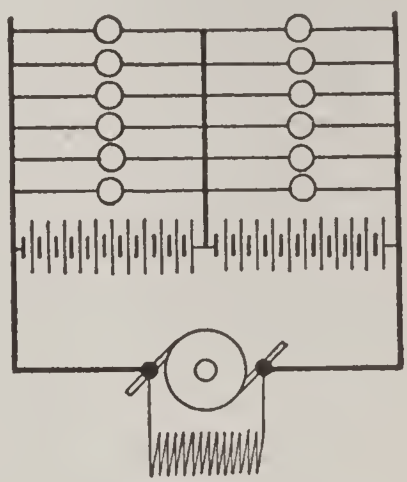


Figure 128

Figures 127 and 128 illustrate other uses for storage batteries. These figures show the elementary connections of batteries used in a manner similar to compensators. It is here made possible by their use to obtain two voltages from one dynamo.

There are so many different types of storage batteries and so many different sizes that it is impracticable to give detailed directions concerning their use. Directions pertaining to any particular battery had best be obtained from the maker.

CHAPTER XV

ARC LAMPS

If we take two suitable pieces of carbon and connect them to a source of electricity and then bring the ends together we shall, of course, obtain a current flow through them. If the contact between the two carbons is not very good, the current will make itself manifest by the heating of the small contact surface to redness. If we now slowly separate these points the current will continue to flow through the intervening air space, forming what is known as the electric or voltaic arc. Where the separation is small the current will be quite strong and a hissing or frying sound will be given out. An arc of this character is generally spoken of as a low tension, or short arc and requires about 25 volts, and, for successful operation, very hard carbons. This type of arc is at the present time very little used for lighting purposes.

If we continue to separate the carbon points the light becomes very unsteady and flickers considerably until at a certain point it begins to improve and we obtain the long, quiet arc. It will now be found that the carbons are separated about 1/8 of an inch. By measuring the difference of potential across this arc we shall find from about 45 to 50 volts and this is the

proper voltage for open arcs. If we continue to increase the separation of the carbons, the arc will grow longer and become decidedly flaming until finally the separation becomes too great and the arc breaks.

The resistance of the arc is very nearly proportional to the cross section of the carbons and increases with an increased separation of the carbon points. The drop in voltage across the arc is not entirely proportional to this resistance, but is also due to a peculiarity of the arc which causes it to act as though a counter E.M.F. was set up in it.

The temperature of the arc is very high, about 3500° Centigrade, and there is nothing that can withstand it. By its help we can drill through the hardest steel or rock or the most effective insulation with equal ease so that, so far, it has been found impossible to construct anything that can resist it.

The light of a strong arc is very injurious to the eyes and has often caused considerable distress and even temporary blindness. This is especially the case where an arc of two or three hundred amperes is used, as for instance, in the drilling of iron beams, or in electric furnaces where upward of 10,000 amperes are sometimes used. Under all circumstances it is best to view the arc through darkened glasses, although the ordinary ten ampere arc will not injure the eye unless it is exposed to the light very long.

The length of the arc, or the space between the carbons, varies from 1/32 of an inch to one inch After a lamp has burned for some time, the carbons will be found to have assumed the shape shown in Figure 129. It will be noticed that the upper, or positive,

carbon has been burned in the form of a crater while the lower carbon has been burned to a point. The crater formed in the upper carbon acts as a reflector and it is from this point that the greatest amount of light, or about 80 per cent of the total light of the arc, is emitted For this reason the positive carbon always occupies the upper position unless, for special reasons, it is desired to throw the greater proportion of the light in an upward direction. It will also be found that the positive carbon burns away about twice as rapidly as the negative carbon. The rapid consump-

Figure 129

tion of the upper carbon is due to the volatilization of the carbon at the crater, considerable vapor being formed at this point which is carried across the arc and condensed on the negative carbon.

If, when the arc lamp is burning in its normal condition, the carbons are separated, it will be found that the upper carbon is heated for a greater distance back from the point than the negative carbon, and it will take longer to cool off. This fact, and the nature of the shadows cast, forms an easy and practical method of determining whether or not, to use the language of the lamp trimmer, the arc is burning right or is

burning "upside down." When the arc is burning with a long separation of the carbon points, the crater almost wholly disappears and the carbons become rounded off.

When arc lamps are used on alternating current circuits a voltage of about 28 is used and the current must be correspondingly increased. Each carbon becomes alternately positive and negative and the two carbons burn to points and are consumed at about the same rate, the difference in consumption between the upper and lower carbon being due to the fact that the heat from the lower carbon rises and increases the carbon consumption of the upper carbon slightly. The alternating current are is much noisier than the direct current arc for all ordinary frequencies, but with very high frequencies this noise ceases. Many lamps cannot be operated on low frequencies such as 25 cycles per second. It is not practicable to operate any of them much below 25 cycles, as the interval during which the current practically ceases becomes of such length that the vapor between the carbon points cools off sufficiently to entirely interrupt the current.

Any arc light is affected by strong drafts of air. This will often literally blow out the arc and cause rapid feeding and short arcs which in turn bring about very rapid consumption of the carbons. A magnet applied to the arc also has the effect of blowing it out and this fact is often made use of in lightning arresters and in connection with some arc machines where the commutator design is such that severe sparking ensues.

While some of the light of the arc is emitted from

the arc itself, it is, especially in open arcs, but a very small proportion of the total light. Most of the light is given out from the carbon points and the quality of the carbon therefore has a great influence on the character of the light If a poor carbon is used, the arc rotates about the carbon, this effect being more noticeable when large carbons are used. Impurities in the carbon will also cause the arc to constantly vary its position and more or less spluttering will occur, accompanied by a constant change in the color of the light.

As a rule, the best carbon is the one that has the greatest range from the point of hissing to the point of flaming. With any given carbon these two points vary with the length of the arc. If the arc runs too short we have the hissing sound, when the arc runs too long it is the flaming that annoys us. It is evident that if carbons can be found to burn without hissing or flaming over a long range, we need not be near so careful with the adjustment of the lamp. As this long range of carbons varies also with their purity, the test for range is also a good test for the light giving qualities of the carbon. As a rule, the greater the range of any carbon the more serviceable it is.

The test for range as usually carried out is made in the following manner: Insert the carbons to be tested in a hand feed lamp. Let them burn with a normal current until they have established the proper points. Now feed them together slowly until the hissing point is reached, and note the voltage across the arc (not the whole lamp). Next, separate the carbons slowly

until they begin to flame, and note this voltage. As has been stated before, the greater the range of voltage through which the carbons can be operated, the better they are. The hissing point is usually about 42 volts, and the flaming point about 62 volts.

To test the comparative life of carbons, it is necessary to observe the quantity consumed by a given current and voltage in a given time. This is best done by arranging that the same current, at the same voltage, shall pass through each arc lamp. Then by weighing, before and after burning, the exact amount of carbon consumed in a given time can be ascertained The approximate useful life of a carbon can be easily determined by burning it for a stated time and observing the amount consumed. The length of the carbon available for burning (not the whole carbon), divided by the length consumed in a given time will give the approximate life of the carbon.

The resistance of carbons is of importance in two ways: first, it consumes energy and, second, some of the forced, high-resistance carbons do not easily strike an arc, i. e., do not volatilize readily enough. The resistance may be measured either with a Wheatstone bridge or with a voltmeter as explained in the chapter on testing. In order to reduce the resistance of the carbons, they are sometimes coated with copper. This will also prolong their life somewhat. Copper coated carbons are more generally used for outside lighting and should never be used on inside lamps unless the arc is entirely enclosed, as hot pieces of copper are thrown off. Another method of reducing the resistance of the carbons is to provide a wire or strip

of metal running through the length of the carbon rod. This scheme is made use of in the flaming arcs where long carbons of small cross section are used.

Cored carbons can be burned at a lower voltage and, if used in conjunction with solid negative carbons will, on direct current, give a very steady arc. The soft core being in the center of the carbon allows that part of the carbon to burn away faster and thus maintain the crater and the arc in one position. Metal electrodes are used in some forms of lamps, various advantages being claimed for them. They always form the negative electrode for, if used on the positive side they are very rapidly consumed.

While there is no definite relation between the size of the carbon and the current, it is evident that there are conditions which must limit us from either extreme. If a small carbon were used with a large current, considerable hissing would result, and the carbon would be rapidly consumed, while with a large carbon and a small current the arc would rotate around the carbon and the light would be very unsteady. The carbon points would not be heated to any great extent and the efficiency would be low. The size of the carbon rods and an outline of the general practice is given in the following table:

ENCLOSED ARC

Volts	Amp.	Upper	Lower
75-80	5	12 in. x $\frac{1}{2}$ in.	$\frac{1}{2}$ in. x $\frac{1}{2}$ in.
to			
80	3	12 in. x $\frac{3}{8}$ in.	6 in. x $\frac{3}{8}$ in.

OPEN ARC

Volts	Amp.	Upper	Lower
45	9.6	11 in. x $\frac{5}{8}$ in.	8 in. x $\frac{1}{2}$ in.
to			
50	6.8	12 in. x $\frac{7}{16}$ in.	7 in. x $\frac{7}{16}$ in.

HAND FEED

Volts	Amp.	Upper.	Lower
45	5-10	6 in. x $\frac{7}{16}$ in.	6 in. x $\frac{7}{16}$ in.
to			
50	25-30	6 in. x $\frac{3}{4}$ in.	6 in. x $\frac{3}{4}$ in.

Arc lamps are generally rated according to candle power. This is a very much abused and misunderstood method of rating. It is evident from an examination of Figure 130 that the candlepower of the arc will depend upon the position from which the measurement of the candlepower is made. Figure 130 will give a general idea of the manner in which this candlepower varies in the case of the ordinary direct current arc. The greatest amount of light is given out at an angle of about 45° with the horizon. Directly above and below the lamp the candlepower is practically nothing, for, in these positions, shadows are cast by the lamp frame. The relative candlepowers at other positions are shown by the length of the radial lines from the center to the curve in the figure.

With alternating current arcs the carbons are al-

ternately positive and negative, and the distribution of light is somewhat different from that of the direct current lamp. The maximum candlepower for an arc consuming the same amount of current is less with an alternating current than with a direct current and

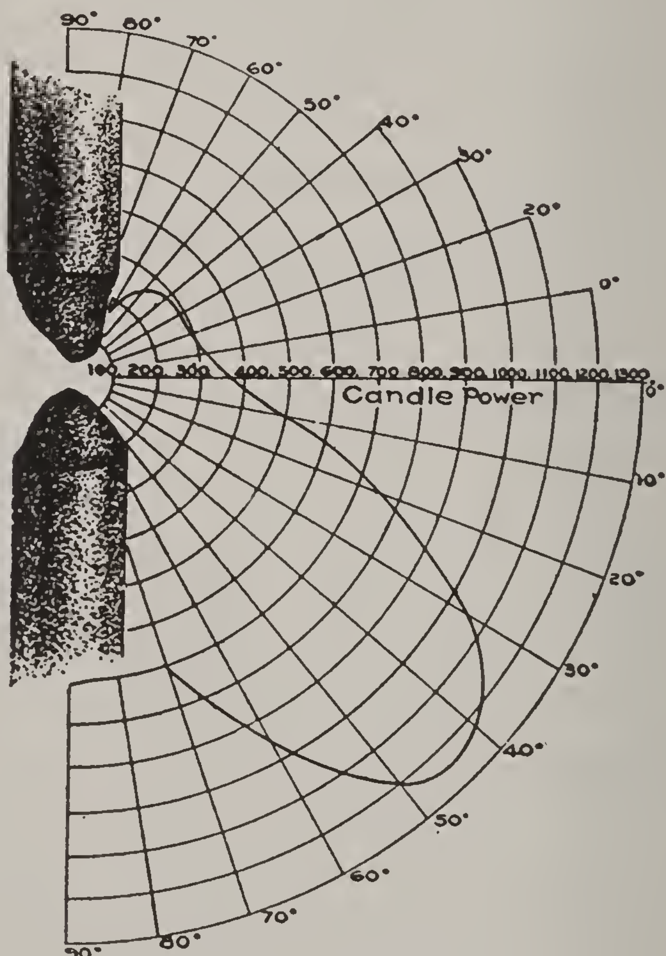


Figure 130

the maximum light is thrown out at different angles. Figure 131 shows the distribution of light from an open, alternating current arc. It will be seen that there are two points of maximum candlepower, one at 40° below the horizontal and the other at 40° above the horizontal.

It is evident from the foregoing description that, to compare the light given out by arc lamps it would be necessary to take into consideration the light given out at all angles above and below the horizontal. This is known as the mean spherical candlepower, and is obtained by taking candlepower readings around the half circle as shown in Figure 130 or Figure 131, and taking the mean. This is given as about one-third the

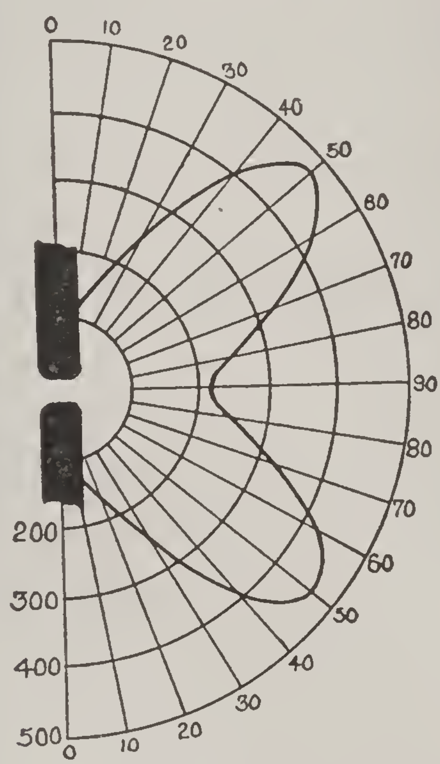


Figure 131

maximum candlepower. For a lamp with a maximum candlepower of 2,000, the mean spherical candlepower would be about 660. The accurate determination of the mean spherical candlepower is a rather difficult procedure and requires the use of special apparatus.

A better method of rating arc lamps now in general use is the wattage rating. The average wattage rating of the various standard lamps is as follows:

9.6 amps., 50 volts, 2000 nominal c. p., 480 watts.
6.8 amps., 50 volts, 1200 nominal c. p., 340 watts.

The proper placing of arc lamps for a given illumination will depend upon the amount of light required. According to many authorities, an expenditure of ½ watt per square foot will give medium illumination such as is used in train sheds while the most brilliant illumination called for can be obtained with 2 watts per square foot. This corresponds to approximately the distances apart as given in the following table:

TABLE B

Medium Illumination			Brilliant Illumination	
Distance Apart	Height		Distance Apart	Height
22 feet	10 to 15 feet	(3 amp. enclosed arcs.)	12 feet	10 feet
30 feet	15 to 20 feet	(6 amp. enclosed arcs.)	21 feet	12 to 15 feet

The higher lamps are hung, the evener will be the illumination.

As a general rule, it is accepted that the distance apart of arc lamps should not be greater than six times their height above the floor. Actual practice, however, in many instances varies widely from this and often the distance apart is 10 or 15 times the height of the lamp, while in other cases only two or three times the height is taken as the distance apart.

With a direct current arc lamp the maximum light is given out at an angle of 45° below the horizontal and very little light is given out in an upward direction. It is evident that a circular area at a distance from the pole equal to the height of the lamp will be very brightly illuminated, and, as we move away from this position the illumination rapidly diminishes. The alternating current arc gives a different distribution of light, the maximum amount of light being given

out at angles of 40° above and below the horizontal. By the use of properly designed reflectors, the light which is given off in an upward direction may be so reflected as to greatly increase the illumination over an extended area and at the same time the bright band of light close to the lamp which is present in the case

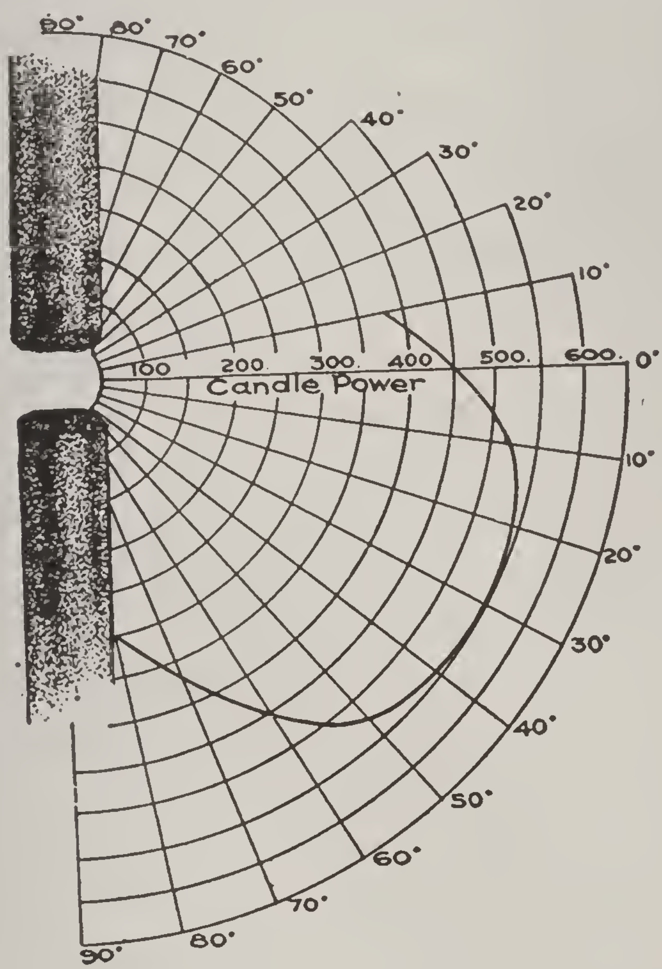


Figure 132

of a direct current lamp is done away with. (See Figure 132.) It is in a measure due to this better distribution of light that the alternating current has come into such general use.

In order to start any arc lamp it is necessary first to bring the carbons together, so that the current can

flow through them and then to separate them to a fixed distance so that the current will be forced to flow through the space separating the carbons and thus produce the arc. There are two general conditions under which this action may take place; one is that of a large number of lamps connected in series, the same current passing through each and the voltage being increased or decreased in proportion as the number of lamps is increased or decreased. The other is that of a single lamp being independently placed in circuit in multiple with other lamps or whatever other devices there may be connected. In the first case each lamp must be equipped with means whereby, should its carbons be burned out or the lamp mechanism otherwise deranged so that current does not flow through the carbons, the current will be automatically shunted around this lamp and continue to feed the balance of the lamps in the circuit, so that only the lamp that is out of order will be left dark.

With the other type of lamp this device is not necessary, because the lamp burns independently of all others and whenever it is out of order there are no other lamps dependent on this circuit for current. As, however, when the carbons are brought in contact the resistance of the lamp circuit is very low, there is likely to be an enormous rush of current through the lamp unless some means of checking it is provided. For this reason every lamp working on an independent circuit must be provided with a resistance cut in series with it which will keep the current from becoming too great while the lamp feeds or the carbons remain together.

In connection with alternating current lamps the same observations apply with the difference that here, instead of a resistance, a reactance is used. The magnet cores are always laminated to reduce the loss and heat due to foucault currents.

The open arc lamp has a number of objectionable features which are causing it to rapidly pass out of use. Owing to the fact that the arc is open this type of lamp is more or less of a hazard when used in proximity to inflammable material. Sparks of hot carbon are thrown off and, if copper coated carbons are used, hot copper is also thrown off. If the lamp is used for inside lighting, such as in a store, for instance, it is absolutely essential that some form of spark arrester be provided. An open arc operates satisfactorily only at from 45 to 50 volts, so that if it is desired to use a lamp of this kind on a 110-volt circuit, a resistance must be provided to reduce the voltage to this amount. This resistance will, of course, consume as much or more energy than the lamp itself, this energy being practically wasted. While two lamps could be operated in series on a 110-volt circuit, this method has not given the satisfaction desired. The open arc must be trimmed, or provided with new carbons, about every 8 to 16 hours, depending on the style of lamp used, and, if the arc is exposed to the weather, they are more or less affected by the wind, a strong wind often blowing the arc out.

All of these objectionable features are overcome in the "enclosed" arc where the carbons, or that part of them in the vicinity of the arc, are completely enclosed in a glass globe. Figure 133 shows the ordi-

nary method of enclosing the arc and, while there are many variations in detail both of the enclosing globe and the cap at the top, the principle of all of them is the same. The glass globe G either sets on an air tight base, or is entirely closed at the bottom The top of the globe is closed by a cap which is provided in the center with an opening through which the upper

Figure 133

carbon descends. This cap is generally arranged to allow of some play sideways so that the carbon will not bind, should it be of slightly irregular shape, and the joints between the cap and the globe are ground smooth so as to exclude the air as much as possible.

When an arc is started in an enclosure of this kind whatever oxygen is present in the inside of the globe is soon consumed and the arc will then be surrounded

by a carbon gas. The absence of oxygen greatly lessens the consumption of carbon, and, with one trimming, the lamp will burn 100 to 150 hours depending on the size and length of carbon used. The presence of this gas also allows of the use of a higher voltage across the arc with a corresponding reduction in the current strength. A steadier light is also obtained.

Another peculiarity of the enclosed arc will be noticed in Figure 133, where it will be seen that the carbons do not burn to points but remain somewhat

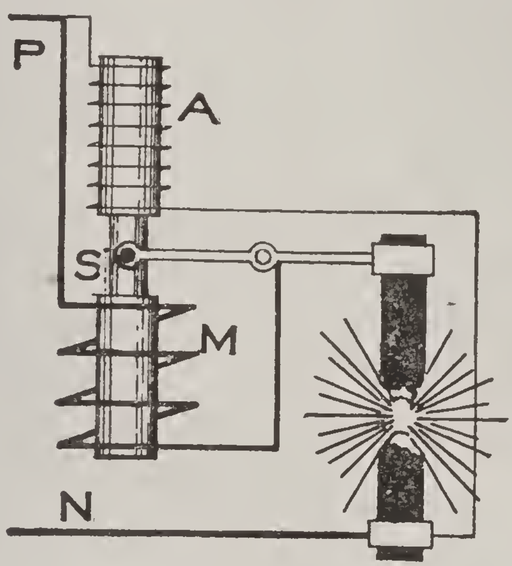


Figure 134

flattened. This results in a better distribution of the light. The enclosed arc requires a voltage of from 72 to 80 volts at the arc, the carbons being separated about 3/8 of an inch, and is, therefore, much better suited for operation in multiple on 110 volt circuits. The arc being completely enclosed, makes the lamp safe for operation in most any location.

The general principles upon which arc lamps are constructed will be explained in connection with the following figures:

Figure 134 shows in simplified form the circuits of the ordinary differential arc lamp. The series coil M (shown by the heavy lines), is connected directly in series with the carbons, while the shunt coil A (shown by the light lines) is connected in shunt around the arc. These coils are so wound and connected that, when energized, they attract the core S in opposite directions, the series coil M tending to draw it down and the shunt coil A up. The movement of the core depends upon the difference between the attraction of the two coils, therefore it is known as the "differential" winding. Any movement of the core S is communicated by means of the lever arm to the upper carbon.

Normally, in this form of lamp, the carbons are in contact when the lamp is not burning. The operation of the lamp is as follows: Current entering at the positive binding post P has two paths by means of which it may get to the negative binding post N. One of these paths is through the high resistance winding A, and the other through the low resistance offered by the series coil M and the two carbons which are in contact. It is evident that the current will take the easier path through the coil M and this coil will then become energized and the core S will be drawn downward, the upper carbon at the same time being raised, separating the carbon points and producing the arc. As soon as the arc is formed more or less resistance, increasing with the length of the arc, is introduced into the circuit of the series coil and some current will now flow through the shunt coil A, energizing this coil and attracting the core S in an upward direction.

Obviously a point will soon be reached where the attraction of the two coils is equalized and the upper carbon will come to rest.

As the upper carbon burns away, and the length of the arc increases, the current through the series coil becomes gradually weaker and that in the shunt coil stronger, with the result that the core is drawn upward and the carbon points approach each other until a balance is again obtained. The mechanism through which the movement of the carbons is effected and the manner of connecting the various circuits differs in the several makes of lamps. Of these methods the following are in more common use.

In some lamps the carbons are carried by a train of clock gears, and this gearing is under control of the two magnets, operating somewhat in the manner described. In other forms of lamps the series magnet lifts the carbons direct and the office of the shunt magnet is simply to close a short circuit around the lifting magnet and thus to deenergize it so that the carbons may feed. This operation is sometimes reversed, the series magnet being short-circuited after the arc has been produced and the movement of the carbon effected by the shunt magnet. In still another style of lamp a small reversible motor is connected to the carbons in such a manner that it may either bring them together or separate them. The motor is provided with two field windings, which oppose each other, and whichever is the stronger determines the direction in which the motor revolves. In connection with any of these plans it is possible to arrange so that the carbons may be either together or separated

when the lamp is at rest. In the first case the first impulse of current separates the carbons, and in the other it must draw them together to start the arc.

The diagram of the connections of a lamp designed to burn on a series circuit with many others is shown in Figure 135. This lamp has the same differential winding as that previously described and in additon is provided with an automatic cut-out, C. It will be

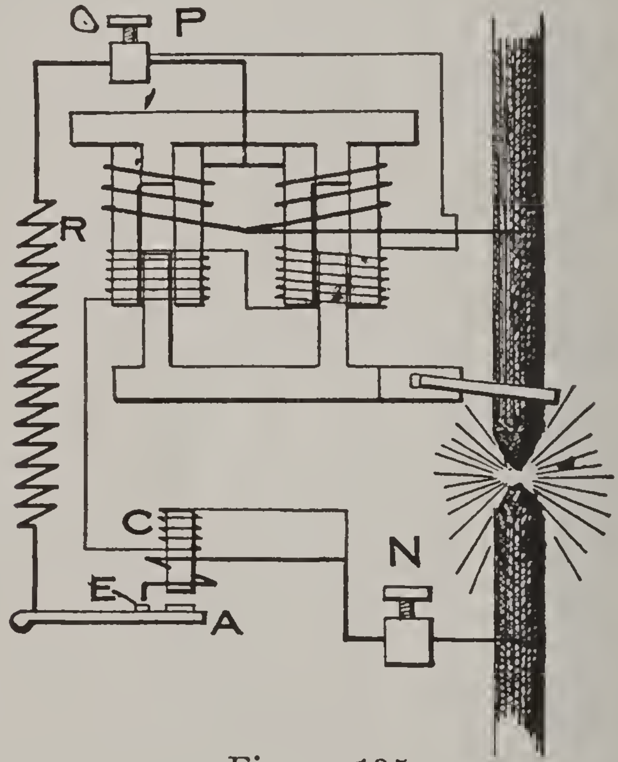


Figure 135

noticed that the magnet winding of this cut-out is in circuit with the shunt coil and the current through it, therefore, increases as the arc grows longer. If the carbons fail to feed, or if the arc grows very long, and in consequence is extinguished, the current flowing through this magnet winding becomes strong enough to cause the armature A to be raised and the circuit at E is closed. The main current now passes

from P, through R, to the armature A, point E, and to the negative terminal N. Thus the current is shunted around the lamp and all other lamps in the circuit are left burning as before. The purpose of R is to maintain some current in the shunt coil. This often starts the lamp again. This style of lamp is never extinguished by opening the circuit, but always by closing a short circuit around the lamp.

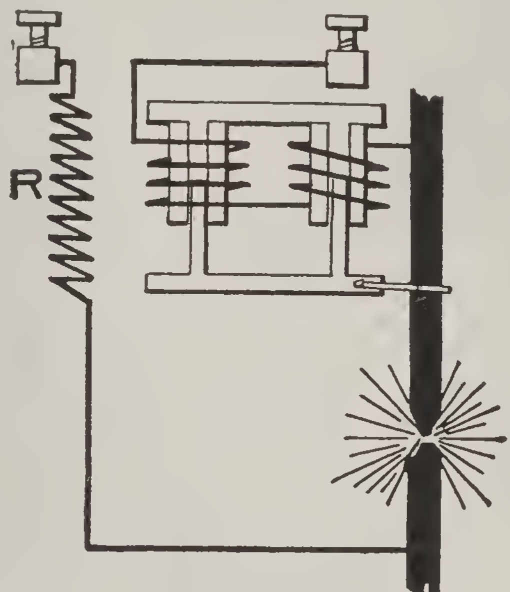


Figure 136

With arc lamps for use on series circuits it is essential for the successful operation of the lamp that both a shunt and series coil be provided. For lamps to be used on multiple circuits, or circuits where the voltage is constant, and where the current flow depends only on the resistance, the lamp will work successfully with either a shunt or series winding. Both windings are not necessary.

Figure 136 shows a type of lamp which is operated with a series winding only. In this case the current

strength varies with the distance apart of the carbons. When the current becomes stronger the magnets become more powerful and draw up the upper carbon, increasing the separation between the carbon points. As the current weakens, the carbons come closer together. This lamp is placed singly in circuit and is

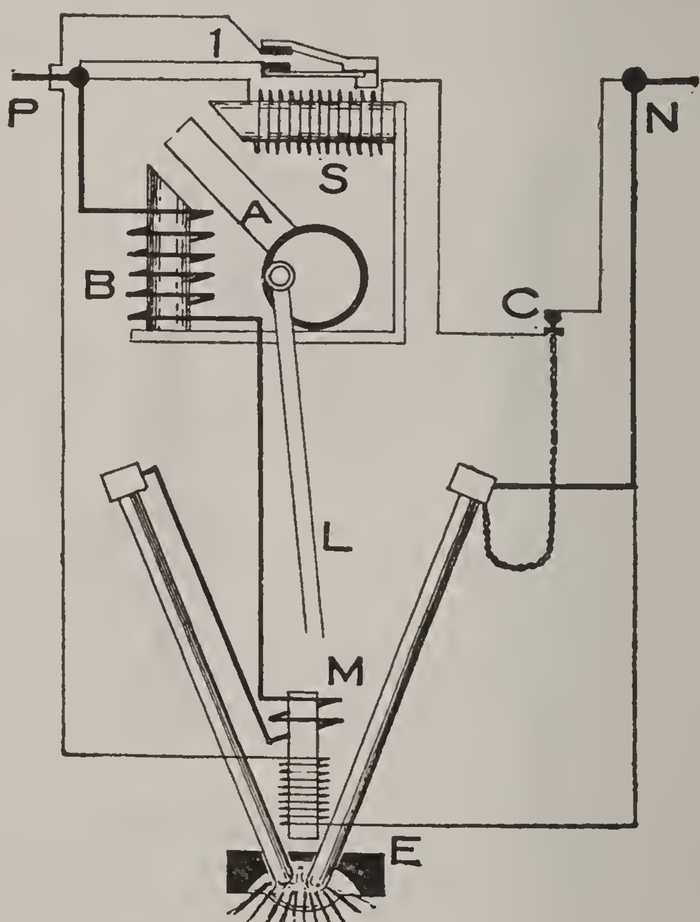


Figure 137

often used on alternating current circuits. R is a reactance which with alternating currents takes the place of the resistance used with direct currents and prevents excessive rise of the current strength when the lamp is started. It is evident that a lamp of this type could not be used on a series. constant current

circuit, for the current flowing through the series coil would never alter and would not be affected by the separation of the carbons. While a lamp controlled only by a shunt coil would operate on either a series or a multiple circuit their use on series circuits is not satisfactory, for when starting the carbons must be separated and the shunt coils of all the lamps are then thrown in series, this necessitating a considerable voltage to start them.

Figure 137 shows the circuits of the flaming arc lamp. In this lamp carbons, the cores of which consist of certain chemicals which give to the arc the peculiar color, are used. A much longer carbon is necessary with this form of lamp and the carbons are of small diameter. The operation of the lamp is as follows: When the lamp is not burning the carbons are separated and no current can pass through them until the shunt magnet S has become energized and pulls over the arm A. As it does so the lever L (by means of mechanism not shown) draws the carbons together and this allows current to flow through them. A very strong current now passes through the series magnet B, drawing the arm A away from the shunt magnet S. This action causes the carbons to be separated and establishes the arc. The resistance of the arc lessens the current flow and consequently weakens the series magnet so that the shunt magnet again comes into action and partially draws the arm A away from the series magnet In this manner a point is soon found at which the arm comes to rest between the two magnets. As the arc burns away the shunt magnet becomes stronger and the series magnet weaker and in

consequence the carbons are brought closer together, i. e., the lamp feeds.

When the carbons have been fully consumed, the small chain shown at the right is drawn down to its limit and opens the shunt magnet circuit at C. This gives the series magnet full control over the arm A and it is drawn all the way over, thus separating the carbons and extinguishing the arc.

The magnet M answers a double purpose. The series winding causes a slight magnetization which tends to force the arc downward away from the economizer E. So long as current passes through the winding of the shunt magnet S the small spring carrying contact is held down and the fine wire circuit around magnet M is open. When, however, the shunt magnet circuit is opened, as by the stretching of the chain, the spring closes the circuit and this causes a strong magnetization to be set up in M which completely extinguishes the arc. This fine wire winding is used only where the arc is operated at high pressure and is not needed on 110 volt circuits.

The operation of this lamp on alternating current circuits is somewhat different from that just described. The carbons rest in contact when the lamp is not burning and, instead of being controlled by the arm A, a small rotor which is under the influence of two opposing magnets is employed. When current is turned on the series magnet controls the rotor and causes it to raise the carbons and strike the arc. When the arc is started the shunt magnet increases in strength and causes the rotor to slow down. As the length of the arc continues to increase the shunt field

becomes strong enough to finally reverse the rotor and feed the carbons together. The method of opening the circuit when the carbons are burned out is about the same as with the direct current lamp. There is no fine wire winding on the blow-out magnet.

OPERATION

The proper care and management of arc lamps requires first of all, that the operator be thoroughly familiar with the principles of operation and all the details of construction of the lamps under his care. It is well, therefore, for the operator to begin by removing the jacket and carefully examine all parts of the lamp so as to thoroughly grasp the purpose and manner of operation of each part. It is also of advantage, if one can safely do so, to watch the operation of the lamp while it is burning.

Lamps are usually trimmed in the following manner: Lower the lamp; remove globe; take out lower carbon; let down upper carbon rod and thoroughly clean it with crocus cloth. The successful operation of the lamp depends to a great extent on the condition of this rod. It must be clean, so that the clutch will firmly grip it. It must not, by any means, be greasy. If the rod becomes dirty it will soon be pitted by the current which passes to it from the contacts inside the lamp and pitting once started rapidly increases. Remove upper carbon and place it in the lower holder. The length of the lower carbon should be measured. A handy manner of doing this is to prepare a gauge of proper length or file a notch in the pliers at the proper point. If the lower carbon is

either too long or too short and the lamp is burned until the upper carbon is entirely consumed, one of the carbon holders will be burned. Place upper carbon in position and align it with the lower by turning it freely about to see that it centers in all positions; raise and lower the upper carbon several times to see that it works freely; clean and replace the globe and raise lamp to its normal position. If circuit is alive test lamp to see that it burns.

It is possible for a good trimmer to take care of 100 or more arc lamps per day, if they are close together. Where they are far apart and conditions are more difficult, 50 lamps will be sufficient.

If the lamp is of the enclosed type, where the lamp clutch feeds the carbon direct, it is necessary to examine the upper carbon to see that it is straight and smooth. Any burs or projections should be removed and the carbon should be raised and lowered to see that it moves freely through the clutch and gas cap.

The care of globes is also of great importance where enclosed arcs are used. Impurities in the carbon are thrown off in the form of a powder, and if this is not removed the useful light of the lamp will be greatly reduced. It is good practice to occasionally return the globe to the shop where they can be thoroughly cleaned. The gas cap must also receive careful attention, for if this does not fit tightly, the operation of the lamp will not be satisfactory.

The following are the principle points to be observed in the handling of arc lamps:

Be sure that the voltage is right for lamps connected

in multiple and the current for lamps connected in series.

Never switch a multiple lamp by shunting the current around it; always open the circuit.

Never open the circuit of a series lamp; always shunt the current around them.

Never try to burn a multiple lamp without an additional resistance in the circuit.

Never place a resistance in the circuit of a series lamp.

Never handle high tension lamps without insulating yourself from the ground.

It is inadvisable to touch the wires on opposite sides of the lamp at the same time. To be safe in this respect confine yourself to working with one hand at a time.

Keep all parts of the lamp clean, especially the rod and the globe.

Provide spark arresters for all open arc lamps where there is inflammable material.

Never leave a lamp without globes where the wind can strike it. The arc will be continually blown out and consume carbons very fast.

If an arc casts shadows or throws considerable light upward, it is an indication that it is burning upside down. To make sure that the lamp is burning upside down, separate the carbons; the one that is red farther from the point is the positive.

A green light coming from the lamp indicates that the carbon holders are being consumed. This will generally occur if the lamp is left burning upside down for a considerable length of time, or if the carbons are not of the proper length.

TESTING

For the testing of an arc lamp practically all that is needed is a reliable voltmeter and ammeter. If series lamps are being tested, it is essential that the machine furnishing current to the testing circuit be in good condition and regulated properly. If a multiple lamp is being tested the voltage of the supply circuit should be constant. The lamp should be located away from draughts of air and with series arcs special precautions must be taken to see that the place upon which the operator stands is well insulated and that under no circumstances can contact be made with the lamp and a ground at the same time. This is of great importance where tests are made on a regular circuit which is in use.

Current and voltage tests can be made and the lamp accurately adjusted to the current and voltage for which it is designed. Detailed instructions are generally given by the manufacturers for the adjustment of each particular type of lamp. These adjustments are generally obtained by altering the connections on the variable resistance or by changing the tension on the springs. Voltage readings should be taken as the lamp feeds and the cut-out if a series lamp, should also be tested to see that the lamp cuts out at the proper voltage. This test is made by slowly separating the carbons until the arc breaks. One of the most common causes of trouble will be found in the cut-out and this should be thoroughly cleaned and tested. A defective cut-out generally results in burned out coils.

SERIES ARC SWITCHBOARDS

The switching of series arc light circuits is a problem altogether different from any other. At the present time, very few new systems of this kind are installed, but there are still quite a number of old installations that must be reckoned with.

Figure 138 shows diagrammatically the well known Thomson-Houston switchboard. In this system there

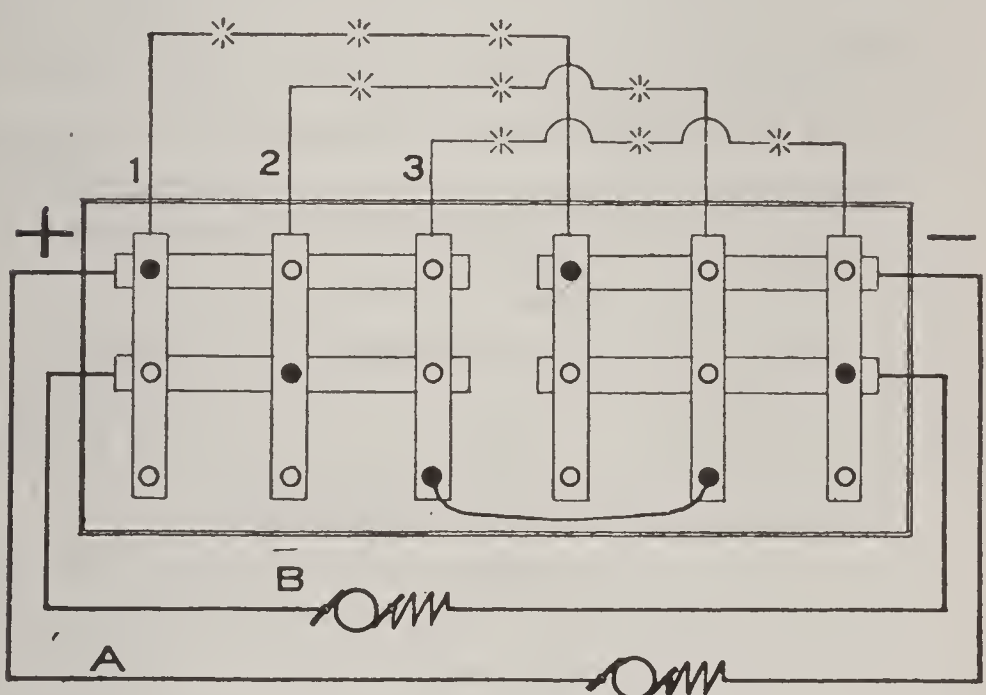


Figure 138

are two horizontal rows of holes, one at the right and one at the left for each machine. There are also two vertical bars containing holes for each circuit on the board. The board may be built for any number of circuits or machines. The lower row of holes is extra and is provided to facilitate connecting several or all of the machines or circuits in series.

The machines are connected to the circuits by means

of plugs which pass through from the front of the board and connect the horizontal bars to the vertical at whatever point a plug may be inserted. If a plug be inserted where the positive side of machine A connects to circuit 1 and another where circuit 1 feeds into the negative side of the same circuit, machine A will be in position to operate this circuit. The position of plugs is indicated by the black circles and by tracing out the circuits it will be seen that machine B is supplying circuits 2 and 3. All of the positive leads of the machines go to one side of the board and the positives of the circuit must be connected to the same side. Whenever it is desired to run several circuits from one machine the negative of the first circuit must be connected to the positive of the next.

If circuit 3 is to be disconnected from machine B, insert plug where circuit 2 crosses bar of machine B, at the right of board. This will put out the light of 3 and the plugs may now be withdrawn.

Another style of switchboard for the same purpose is shown in Figure 139. Here the connections from machine to circuit and from circuit to circuit are made by flexible cables, which carry suitable plugs at each end. In this diagram machine A is supplying circuit 1 and machine B circuits 3 and 4. Three holes are provided at the terminals of each circuit and machine to allow of the use of auxiliary plugs in switching. If circuit 2 is to be added to machine A, auxiliary plugs are used as shown by dotted lines. The main cable C from minus side of circuit 1 may now be withdrawn. This will force current through circuit 2 and the permanent plugs may now be placed

in the center of the holes. If circuit 2 should contain many lights or be open, a long flash would accompany the withdrawal of the plug.

To disconnect circuit 3 from machine B insert auxiliary plug, as indicated by broken line and withdraw cables D and E.

When it is desired to dispense with one of the machines and let the other do all of the work, the transfer can be made without disturbing the lights by first

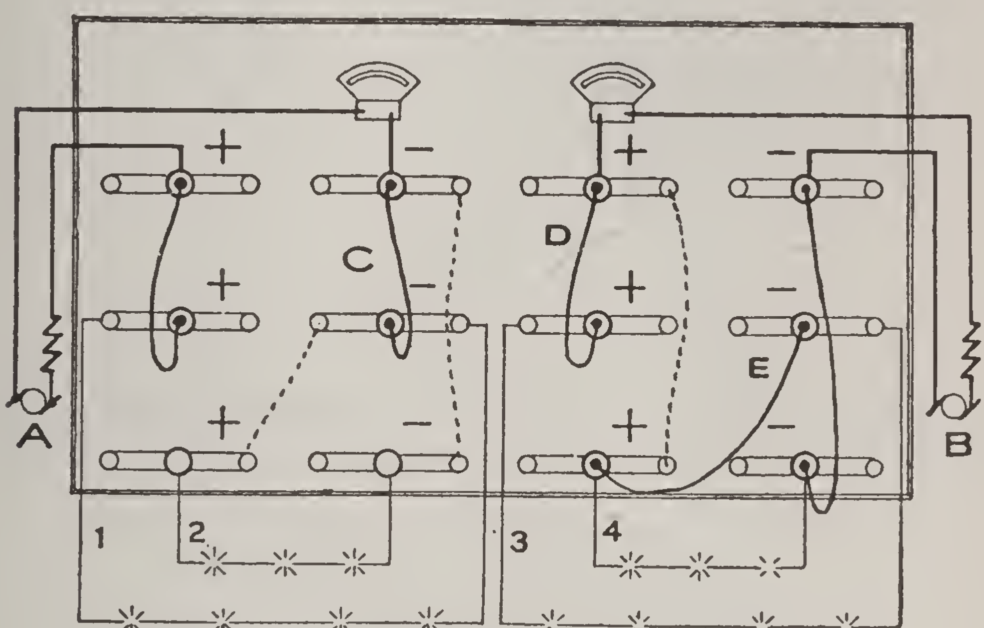


Figure 139

connecting the two machines in series on all of the circuits in use. When this is done, short circuit the fields of the machine A that is to be cut out, and then short circuit the whole machine and disconnect it.

Switching arc circuits is somewhat confusing to one who is not familiar with it, and it is advisable for any beginner to study out the best methods for the particular board with which he has to work. He should

have the whole system in his head so as to avoid the necessity of studying over the problem when circuits are to be changed in a hurry.

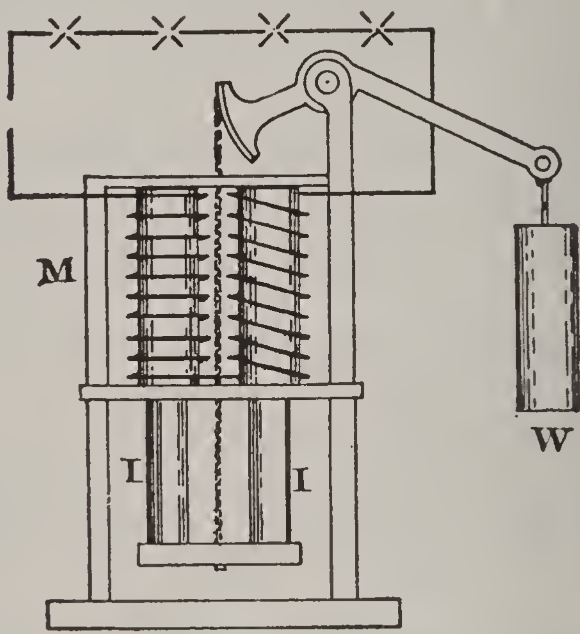


Figure 140

Figures 140 and 141 show methods of controlling alternating current arcs operating in series. In Figure 140 the weight W balances the two cores of the coils M. When a current passes through these coils they draw in the cores and in so doing increase the

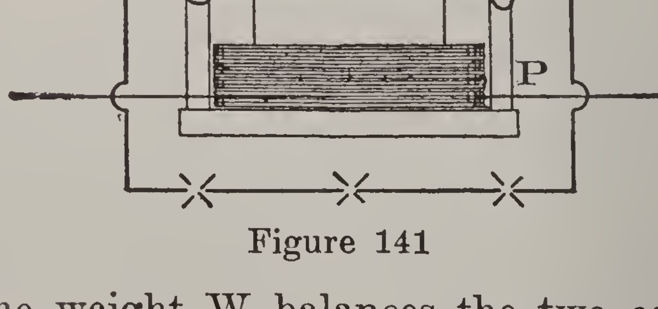


Figure 141

reactance of the circuit. This in turn cuts down the current. In the above manner the device automatically regulates the current and keeps it very close to its predetermined value. This device is used only for constant current arc lamps.

A somewhat different principle is employed in Figure 141. In this figure P is the primary coil of a series transformer and the current from the generator always passes through it. This current induces secondary currents in the coil S. This coil is balanced by the weights W, and is free to move up or down. If the current in the secondary increases beyond a predetermined amount, the repulsion between the two coils is increased and the upper one rises. This lessens the induction and cuts down the current. If the current becomes weak, the operation is reversed.

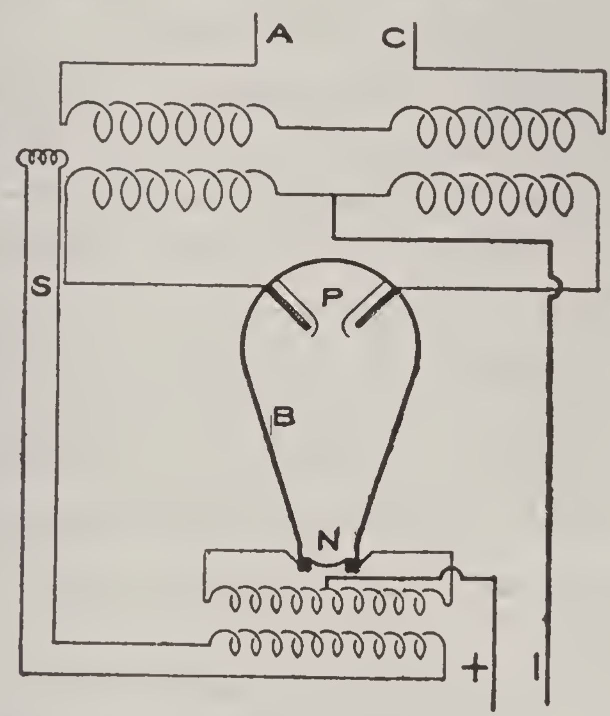


Figure 142

Where it is desired to use direct current arc lamps from alternating current circuits, the Cooper-Hewitt Mercury Rectifier is often used. A diagram of the connections of this device is shown in Figure 142. The principle upon which this is based is outlined in another chapter and need not be repeated here. It is well known that the current can pass from the positive electrodes P into the negative or mercury electrodes N when once established, but cannot pass from the negative electrode to the positive.

In order to start the operation, the glass bulb is tilted a little so that the mercury of the two lower electrodes unites; this starts current from the starting transformer S and when the bulb is returned to its normal position the current breaks, causing an arc. This allows current from whichever of the upper electrodes is positive at the time, to pass into the negative and feed the arc lamps. As the polarity of the upper electrodes unites; this starts current from the starting negative ceases and that from the one that is now positive begins.

A reactance which will cause the current from the first pole to overlap that of the succeeding one must be provided, or the current will cease entirely should it ever go to zero.

CHAPTER XVI

INCANDESCENT LAMPS

For the illumination of small spaces such as offices, residences, etc., the incandescent lamp is without doubt the most useful and economical. This is principally due to the even distribution of light which the small units make possible, and to the readiness with which the lamps may be adapted to numerous lighting schemes.

Originally all commercial incandescent lamps were made with carbon filaments, but within the last few years new types of filaments have been developed and these are, to a great extent, replacing the carbon filament.

In the carbon filament lamp a filament or thread is formed of some material rich in carbon, fibers of bamboo being originally used for this purpose. At the present time practically all carbon filaments are made by forcing a cellulose compound through suitable dies, the filament being hardened, cut to the proper length and placed on forms. It is then entirely surrounded by carbon in some form, so as to exclude all air and heated for several hours in a furnace.

After it is cooled the filament is removed from the form and connected to the leading in wires. The

substance of which the leading in wires is composed must expand and contract at the same rate as the glass surrounding it, otherwise the glass would be broken or a space would be left where the air could enter the lamp. This substance must also be of such a nature as to withstand the high temperature at which the glass is fused and the heat of the filament. Platinum is about the only material that fulfills these conditions and is used for this purpose.

The filament is now subjected to what is known as the "flashing" process, being placed in a chamber filled with a hydrocarbon vapor and current passed through the filament until it is heated to a low degree of incandescence. Any irregular portions of the filament will be heated to a higher temperature and carbon will be deposited to a greater extent at these points. When all parts are uniform and the filament is of the proper resistance, the process is stopped. In good lamps heated to a dull red, the filament should appear uniform throughout. If there are bright spots the filament will quickly burn out at one of these places.

After flashing the filament appears gray in color, with a hard outer surface which increases the useful life of the lamp and adds to its efficiency.

The filament is now placed in the glass globe and the air is then exhausetd by mechanical or chemical means. A good vacuum is of great importance. The presence of oxygen hastens the deterioration of the filament. The presence of any gas inside the lamp increases the loss of heat in the filament and therefore reduces its efficiency. This also increases the de-

terioration of the filament through friction between the filament and the gas. In a poor vacuum vibration of the filament will cease quickly.

Incandescent lamps are rated according to their candlepower, the sixteen-candlepower lamp being the size most generally used. The lamp is also made in various sizes from 2 to 50-candlepower.

The light given out by an incandescent lamp bears a certain definite relation to the temperature of the filament, being greater as the temperature of the filament is increased. The current taken by the lamp depends upon the resistance offered by the hot carbon filament. It can readily be seen that we might have two incandescent lamps, each giving out a light equivalent to 16-candlepower, but one taking considerable more current than the other, as, for instance where one lamp has a short filament of small cross section and the other a long filament of larger section. It is evident that to intelligently compare lamps, the relation between the amount of energy consumed and the amount of light given out by the lamp must be known. This is termed the "efficiency" of the lamp, and is obtained by dividing the total watts consumed by the lamp by the candlepower.

$$\frac{\text{Total Watts}}{\text{Candlepower}}$$

If a lamp consumes 56 watts and gives a candlepower of 16, the efficiency is $56 \div 16 = 3.5$ watts per candle.

It may be noted that the term "efficiency" is somewhat of a misnomer as here used. A 16-candlepower

lamp consuming 50 watts, has an efficiency of 3.1, the efficiency in this case as expressed numerically being less than in the case previously stated, while, as a matter of fact, the real efficiency of the lamp is higher as it consumes fewer watts per candle. Nevertheless, the term has come into general use and when expressed in a certain number of watts per candle conveys the actual comparative rating of the lamp. Low candlepower lamps are generally less efficient than the standard sizes and the 220-volt lamps are less efficient than those of 110. Table I shows the wattage and current for lamps in general use.

The efficiency in lamps of the same type of filament depends upon the temperature of the filament. The higher the temperature the brighter the filament and the less the number of watts per candle. A temperature of about 2500° F., is maintained in the carbon filament. After a lamp has been in use for some time the filament gradually disintegrates, the carbon which is thrown off by the filament depositing on the inside of the glass globe. The light emitted from the lamp is thereby greatly reduced and the watts per candle increased. The disintegration of the filament is more rapid the higher the temperature.

TABLE I.

RATING OF INCANDESCENT LAMPS.

C. P.	Watts	Amperes
Carbon Lamps, 110 Volts.		
2	13	.11
4	18	.16
6	24	.22
8	30	.27
10	35	.32
12	40	.36
16	56	.51
20	70	.64
24	84	.76
32	112	1.00
50	175	1.60
Carbon Lamps, 220 Volts.		
C. P.	Watts	Amperes
8	36	.16
10	45	.20
16	64	.29
20	76	.35
24	90	.41
32	122	.55
50	190	.86
Gem Lamps, 110 Volts.		
C. P.	Watts	Amperes
20	50	.45
40	100	.91
50	125	1.14
75	187	1.70
100	250	2.27
Tantalum Lamps, 110 Volts.		
C. P.	Watts	Amperes
20	40	.36
40	80	.73
Tungsten Lamps, 110 Volts.		
C. P.	Watts	Amperes
32	40	.36
48	60	.55

It is evident from the foregoing that there are two main factors effecting the usefulness of an incandescent lamp. By increasing the efficiency we shorten the life and by decreasing the efficiency we increase the life of the lamp A lamp taking 3.5 watts per candle has a useful life of about 800 hours. By burning the lamp at 4 watts per candle the life of the lamp would be extended to about 1,800 hours.

The cost of current will generally determine the proper lamp to use. When the cost of current is low, a low efficiency lamp may be used, and when the cost of current is high, a high efficiency lamp should be used. A point to be considered in the use of high efficiency lamps is the pressure or voltage at which the lamp is burned. For economical and satisfactory operation, the pressure must be maintained practically

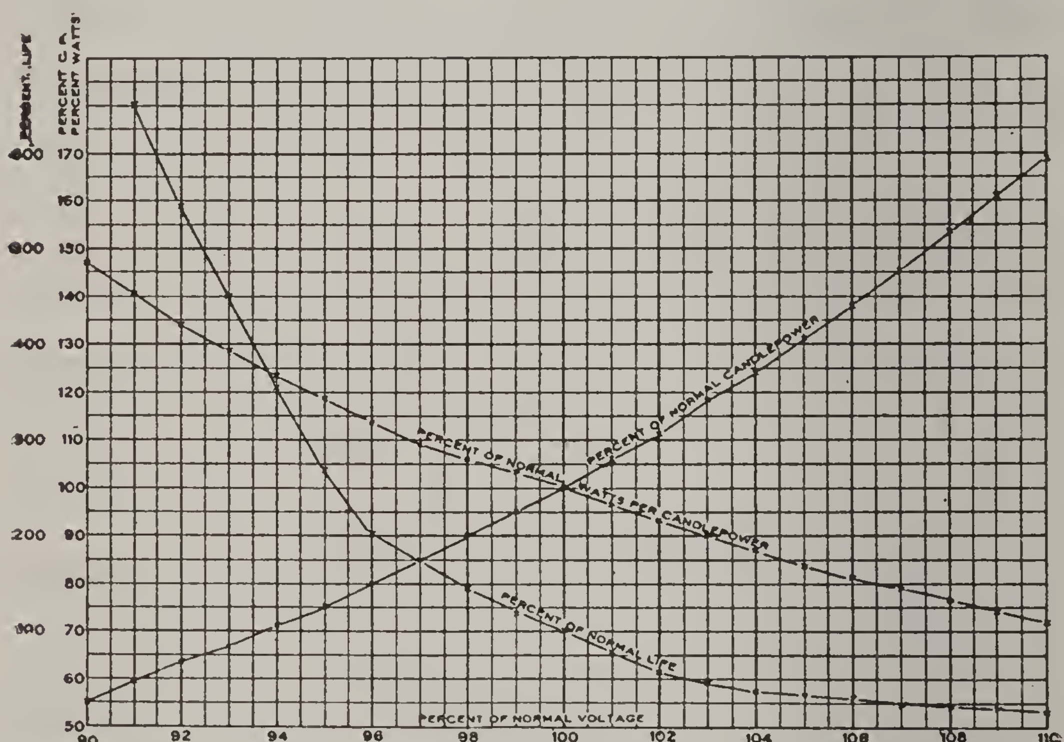


Figure 143

uniform. With the filament already at a high temperature even a slight increase in voltage will produce a considerable increase in the temperature of the filament and a corresponding decrease in the life. This is not of so much importance where low efficiency lamps are used as a slight increase in the voltage does not produce such an excessive rise in the temperature of the filament.

The manner in which the candlepower, watts per candle, and the life of 3.5 watt carbon lamps vary where burned at voltages greater or less than their normal voltage is shown in Table II, which table is given by the Westinghouse Co. and represents the average of a number of tests. The values given in the table are plotted on the curves in Figure 143. It will be noted that an increase of 3 per cent in the voltage reduces the life of the lamp to one-half, while an increase of 6 per cent decreases the life to one-third.

TABLE II.

INCANDESCENT CARBON LAMPS.

Effect of Variation of Voltage on Candle Power, Efficiency and Life.

Volts	Candle Power	Watts per Candle	Life
Per cent.	Per cent.	Per cent.	Per cent.
110	169	72	15
109	161	74	18
108	153	76.5	21
107	145	79	24.5
106	138	81.5	29
105	131	84	34
104	124	87	40
103	118	90	48
102	111	93	60
101	106	96.5	80
100	100	100	100
99	95	103	120
98	90	106	147
97	85	109.5	175
96	80	113.5	200
95	75	118.5	270
94	71	123.5	355
93	67	128	450
92	63	134	545
91	59	140.5	650
90	55	147.5	760

As an illustration of the use of the table assume the case of a 16-C. P., 110-volt lamp consuming 3.5 watts per candle and having a life of 800 hours. If a lamp of this rating was burned on a circuit where the

voltage was 120, or 109 per cent of its normal voltage, the candlepower would be increased to 161 per cent of the normal or 25.8 C. P.; the watts per candle would be reduced to 74 per cent, or about 2.59; the life would be decreased to 18 per cent, or 144 hours.

If a 16-C. P., 3.5 watt lamp, designed for use on an 115-volt circuit, was burned on a circuit at 110 volts or 95.5 per cent of the normal, the candlepower would be decreased to 77.5 per cent or 12.4; the watts per candle to 116 per cent, or about 4; the life increased to 237 per cent, or about 1,880 hours.

It is an inexcusable, though very natural, mistake to suppose that there is any economy in burning lamps after their candlepower has been greatly reduced. As a rule, if a lamp be burned about 1,000 or 1,200 hours the candlepower will have fallen to one-half of its initial value, while the current consumption will remain about the same. Consider the following example: A 50-watt lamp burning 600 hours will consume 30,000 watts, which at ten cents per kilowatt will cost \$3.00. The cost of the lamp will not be more than 20 cents. If now the lamp be burned for 600 hours more, it will give out about 8 candlepower and the cost of the current consumed will be another \$3.00, whereas the cost of a new lamp of 8 candlepower, which would give its equivalent in light, would cut the cost of current down to one-half or \$1.50 and the cost of the new lamp would be only 20 cents. It will be seen that the user, who is trying to save something by getting along with a dim light, is losing half his light to save 20 cents, and at the same time paying out \$1.30 more than would be required to obtain the same

illumination with a new lamp of the same candlepower as the old one is actually giving him.

The useful life of a lamp is determined by the number of hours the lamp will burn before the candlepower has dropped to 80 per cent of its original value. This is known as the "smashing point," and it is seldom economical to burn the lamp after this point has been reached.

When lamps become old and dim, the candlepower can be increased by increasing the voltage, but this is poor practice for, of necessity, the voltage on whatever new lamps may be in circuit is also increased and this does more harm in shortening the life of these lamps than good in saving the old.

The efficiency and the life of incandescent lamps are two factors which do not harmonize. The higher the efficiency of a carbon filament lamp the shorter its life. This makes it advisable to carefully consider which is the most economical lamp to use. The two main considerations in determining the most economical lamp are the cost of current and the cost of lamp renewals. Tables III and IV are prepared to facilitate calculation in this regard. The most economical lamp to use is that in which the cost of energy and the cost of renewals is a minimum. If the cost of power is high, a lamp of high efficiency, even though its life be short, is generally more economical; while if power is very cheap, a lamp of low efficiency is generally advisable.

TABLES

In Table III, the cost of current per kilowatt is given at the top of the columns, and the watts per

candlepower of the lamp in the left-hand vertical column. Wherever two columns cross will be found the cost per candlepower for 1,000 hours for the lamp of an efficiency as indicated in the left-hand column, and at the cost per kilowatt as shown at the top of the column. As an example: Take a lamp of an efficiency of 3.1 watts per candle, with current costing 10 cents per kilowatt. Where these two columns intersect in the table will be found the value, .310; showing that the cost per candlepower per 1,000 hours at this efficiency and rate will be 31 cents.

To ascertain the cost of current consumed by a lamp of any candlepower per 1,000 hours, the cost as found in the table must be multiplied by the candlepower of the lamp. For instance: a 16-candlepower lamp at the rating shown above, would cost 16 × .31 = \$4.96 for 1,000 hours burning.

Table IV deals with the cost of lamp renewals. In the upper horizontal row is given the life of the lamp in hours, and at the left hand vertical column the cost of the lamp in cents per candlepower. Wherever the two columns cross will be found the cost of lamp renewals per 1,000 hours.

Example: Suppose a 16-candlepower lamp costs 19 cents (1.2 cents per candle) and has a life of 600 hours. In the row at the right of 1.2, and in the column headed 600 will be found the value, .02, which is the cost of the lamp renewals per candlepower for 1,000 hours. For a 16-candlepower lamp, the cost would be 16 × .02 = \$0.32. The total cost of the lamp for 1,000 hours, including both cost of current and renewals, is \$4.96 + \$0.32 = \$5.28.

TABLE III.

COST OF RENEWALS PER CANDLEPOWER PER 1000 HOURS.

Cost of Lamp per Candlepower—Cents.	Life of Lamp in Hours. 1200	1150	1100	1050	1000	950	900	850	800	750	700	650	600	550	500	450	400	350	300	250	200	150
.5	.004	.004	.004	.005	.005	.005	.006	.006	.006	.007	.007	.008	.008	.009	.01	.011	.012	.014	.017	.02	.025	.033
.6	.005	.005	.005	.006	.006	.006	.007	.007	.007	.008	.009	.009	.010	.01	.012	.013	.015	.017	.02	.024	.03	.04
.7	.006	.006	.006	.007	.007	.007	.008	.008	.008	.009	.01	.011	.012	.013	.014	.016	.017	.02	.023	.028	.035	.047
.8	.007	.007	.007	.008	.008	.008	.009	.009	.01	.011	.011	.012	.013	.015	.016	.018	.02	.023	.027	.032	.04	.053
.9	.007	.008	.008	.009	.009	.009	.01	.011	.011	.012	.013	.014	.015	.016	.018	.02	.022	.026	.03	.036	.045	.06
1.0	.008	.009	.009	.010	.01	.011	.011	.012	.012	.013	.014	.015	.017	.018	.02	.022	.025	.029	.033	.04	.05	.067
1.1	.009	.010	.010	.010	.011	.012	.012	.013	.014	.015	.016	.017	.018	.02	.022	.024	.027	.031	.037	.044	.055	.073
1.2	.010	.010	.011	.011	.012	.013	.013	.014	.015	.016	.017	.018	.02	.022	.024	.027	.03	.034	.04	.048	.06	.08
1.3	.011	.011	.012	.012	.013	.014	.014	.015	.016	.017	.019	.02	.022	.024	.026	.029	.032	.037	.043	.052	.065	.087
1.4	.012	.012	.013	.013	.014	.015	.016	.016	.017	.019	.02	.022	.023	.025	.028	.031	.035	.04	.047	.056	.07	.093
1.5	.012	.013	.014	.014	.015	.016	.017	.018	.019	.02	.021	.023	.025	.027	.03	.033	.037	.043	.05	.06	.075	.10
1.6	.013	.014	.015	.015	.016	.017	.018	.019	.02	.021	.023	.025	.027	.029	.032	.036	.04	.046	.053	.064	.08	.107
1.7	.014	.015	.015	.016	.017	.018	.019	.02	.021	.023	.024	.026	.028	.031	.034	.038	.042	.049	.057	.068	.085	.113
1.8	.015	.016	.016	.017	.018	.019	.02	.021	.022	.024	.025	.028	.03	.033	.036	.04	.045	.051	.06	.072	.09	.12
1.9	.016	.016	.017	.018	.019	.02	.021	.022	.024	.025	.027	.029	.032	.035	.038	.042	.047	.054	.063	.076	.095	.127
2.0	.017	.017	.018	.019	.02	.021	.022	.024	.025	.027	.029	.03	.033	.036	.04	.044	.05	.057	.067	.08	.10	.133
2.2	.018	.019	.020	.021	.022	.023	.024	.026	.027	.03	.031	.034	.037	.04	.044	.049	.055	.063	.073	.088	.11	.146
2.4	.020	.021	.022	.023	.024	.025	.027	.028	.03	.032	.034	.037	.04	.044	.048	.053	.06	.069	.08	.096	.12	.16
2.6	.022	.023	.024	.025	.026	.027	.029	.031	.032	.035	.037	.04	.043	.047	.052	.058	.065	.074	.087	.104	.13	.173
2.8	.023	.024	.025	.027	.028	.029	.031	.033	.035	.037	.041	.043	.047	.051	.056	.062	.07	.08	.093	.112	.14	.186
3.0	.025	.026	.027	.029	.03	.032	.033	.035	.037	.04	.043	.046	.05	.055	.06	.067	.075	.086	.10	.12	.15	.20
3.5	.029	.030	.032	.033	.035	.037	.039	.041	.044	.047	.05	.054	.058	.064	.07	.078	.087	.10	.117	.14	.175	.233
4.0	.033	.035	.036	.038	.040	.042	.044	.047	.05	.053	.057	.062	.067	.073	.08	.089	.10	.114	.133	.16	.20	.266
4.5	.037	.039	.041	.043	.045	.047	.05	.053	.056	.06	.064	.069	.075	.082	.09	.10	.112	.129	.15	.18	.225	.30
5.0	.041	.043	.045	.048	.05	.053	.056	.059	.062	.067	.071	.077	.083	.091	.10	.111	.125	.143	.166	.20	.25	.333
5.5	.046	.048	.050	.052	.055	.058	.061	.065	.069	.073	.079	.085	.092	.10	.11	.122	.137	.157	.183	.22	.275	.366
6.0	.050	.052	.055	.057	.06	.063	.067	.071	.075	.08	.086	.092	.10	109	.12	.133	.15	.171	.20	.24	.30	.40
6.5	.054	.056	.059	.062	.065	.068	.072	.076	.081	.087	.093	.10	.106	.118	.13	.144	.162	.186	.216	.26	.325	.433

TABLE IV.

COST OF CURRENT PER CANDLEPOWER PER 1000 HOURS.

Watts per Candlepower.	Price per Kilowatt in Cents. 2	2½	3	3½	4	4½	5	6	7	8	9	10	11	12	14	16	18	20
1.	.020	.025	.030	.035	.040	.045	.050	.060	.070	.080	.090	.100	.110	.120	.140	.160	.180	.200
1.25	.025	.031	.037	.048	.050	.056	.062	.075	.087	.100	.112	.125	.137	.150	.175	.200	.225	.250
1.5	.030	.037	.045	.052	.060	.067	.075	.090	.105	.120	.135	.150	.165	.180	.210	.240	.270	.300
1.75	.035	.044	.052	.061	.070	.079	.088	.105	.122	.140	.158	.175	.192	.210	.245	.280	.315	.350
2.	.040	.050	.060	.070	.080	.090	.100	.120	.140	.160	.180	.200	.220	.240	.280	.320	.360	.400
2.25	.045	.055	.067	.075	.090	.100	.112	.135	.152	.180	.202	.225	.247	.270	.315	.360	.405	.450
2.5	.050	.062	.075	.087	.100	.112	.125	.150	.175	.200	.225	.250	.275	.300	.350	.400	.450	.500
2.65	.053	.066	.079	.093	.106	.119	.132	.159	.185	.212	.238	.265	.292	.318	.371	.424	.478	.530
2.8	.056	.070	.084	.098	.112	.126	.140	.168	.196	.224	.252	.280	.308	.336	.392	.448	.504	.560
3.	.060	.075	.090	.105	.120	.135	.150	.180	.210	.240	.270	.300	.330	.360	.420	.480	.540	.600
3.1	.062	.077	.093	.108	.124	.139	.155	.186	.217	.248	.279	.310	.341	.372	.434	.496	.558	.620
3.5	.070	.087	.105	.122	.140	.157	.175	.210	.245	.280	.315	.350	.385	.420	.490	.560	.630	.700
4.0	.080	.100	.120	.140	.160	.180	.200	.240	.280	.320	.360	.400	.440	.480	.560	.640	.720	.800
4.5	.090	.110	.135	.150	.180	.200	.225	.270	.305	.360	.405	.450	.495	.540	.630	.720	.810	.900
5.0	.100	.125	.150	.175	.200	.225	.250	.300	.350	.400	.450	.500	.550	.600	.700	.800	.900	1.00
5.5	.110	.137	.165	.193	.220	.248	.275	.330	.385	.440	.495	.550	.605	.660	.770	.880	.990	1.10
6.0	.120	.150	.180	.210	.240	.270	.300	.360	.420	.480	.540	.600	.660	.720	.840	.960	1.08	1.20
6.5	.130	.182	.195	.227	.260	.292	.325	.380	.455	.520	.595	.650	.715	.780	.910	1.04	1.17	1.30

To find the most economical lamp where the cost of current is fixed, it is only necessary to try out several cases and select the one where the sum of the two fac-

tors is a minimum. In comparing lamps of either the same or different candlepowers, it is not necessary to multiply the values found in the tables by the candlepower of the lamp. On the other hand, where the actual cost per 1,000 hours is desired, the values found in the tables must be multiplied by the candlepower of the lamp in question.

As an example showing the method in which the table is used the two following lamps will be compared:

Sixteen-candlepower carbon lamp of an efficiency of 3.5 watts per candle, life of the lamp 1,150 hours, cost of the lamp 16 cents (1 cent per candle).

Thirty-two-candlepower Tungsten lamp of an efficiency of 1.25 watts per candle, life of lamp 1,000 hours, cost $1.20 (3.7 cents per candle).

Cost of current, 10 cents per kilowatt.

For the carbon lamp:

Table III gives	.35
Table IV gives	.009
Total	.359

For the Tungsten lamp:

Table III gives	.125
Table IV gives	.035
Total	.160

The result shows that for the values taken the cost of the Tungsten lamp will be less than one-half that of the carbon lamp.

It will be noted that in using the tables, the cost per candlepower of the Tungsten lamp is 3.7 cents is not given in the table, and the value 3.5 is taken. If greater accuracy is desired, the values may be interpolated. For instance: in the case given, the value from Table IV would be .037, giving a total of .162 in place of .160.

Arc lamps, Nernst lamps, or, in fact, any lamps where the candlepower, efficiency and cost are known may be compared; either two lamps of the same type, or lamps of different types.

METALLIZED FILAMENT LAMP

In the past few years a number of new types of incandescent lamps have been developed. The quality of the light, the life of the lamp, its regulation and its efficiency have all been greatly improved. The first of these lamps to come into general use is known as the metallized filament lamp. The filament of this lamp is of carbon, which is put through various processes, one of which is the heating of the filament to a very high degree in an electric furnace. Practically all the impurities are driven out by this process and a greatly increased efficiency is obtained, and the filament gives out a much better quality of light.

One of the peculiar results effected by the treatment of the filament, and the one from which it gets its name, is that the electrical characteristics of the carbon is considerably changed. The ordinary carbon filament has a negative temperature coefficient; in other words, its resistance lowers with an increase in

temperature and increases with a lowering temperature. On a system where the voltage regulation is poor, the effect of the negative temperature coefficient is, so far as the light is concerned, cumulative, the increase in voltage causing, in itself, more current to flow through the lamp, increasing its candlepower. The increase in current increases the temperature of the filament and lowers its resistance, this causing a still further increase in the candlepower.

The metallized filament has a positive temperature coefficient, similar to metals. Its resistance increases as its temperature increases. The regulation of the lamp is therefore much better than that of the carbon lamp, an increase in voltage causing an increase in the resistance of the filament and a corresponding tendency to check the current rise. This lamp has an efficiency of 2.5 watts per candle, or 40 watts for a 16-candlepower lamp.

TANTALUM LAMP

The Tantalum lamp is another recent development in the field of incandescent lighting. This lamp takes its name from the metal from which the filament is constructed. Tantalum is one of the rare metals and not only has a greater strength than steel, but is capable of withstanding a very high temperature. Due to these characteristics the metal is very well suited for use as a filament.

As all metals are of comparatively low resistance a filament of unusual length must be employed to obtain the proper resistance. The Tantalum lamp has

an efficiency of 2 watts per candle and gives a very white light resembling daylight. It is not recommended for use on alternating current circuits.

TUNGSTEN LAMPS

Shortly after the introduction of the tantalum lamp a still greater advance was made by the bringing out of the Tungsten lamp. Tungsten, another of the rare metals, is in its electrical behavior similar to tantalum but for use as a filament it surpasses tantalum, owing to the fact that its melting point is considerably higher. The filament can be burned at a very high temperature and has an efficiency of 1.25 watts per candle. The filament being of metal has a comparatively low resistance and, as with tantalum, must be unusually long to obtain the proper resistance for use on the common voltages.

The current required for producing equal candlepower with Tungsten lamps is approximately one-third of that required by carbon lamps, and approximately one-half of that required by the metallized filament lamps. The cost of operating Tungsten lamps is, therefore, much less than the cost of operating other lamps.

The light given by the Tungsten lamp is much whiter and more pleasing in character than that given by other lamps. As its quality corresponds more nearly to sunlight than any other artificial illuminant it is especially desirable for use in show rooms, stores, etc. The loss in candlepower after the lamp is in use for some time amounts to about one-fourth that of the

carbon lamp. The lamp also has a much longer life than the carbon lamp. In regulation the Tungsten lamp is greatly superior to the carbon lamp and an excessive voltage which would ruin a carbon lamp does not seriously affect the Tungsten lamp.

Tungsten being quite brittle and the filament of necessity being of small cross section, the lamp must be carefully handled. The lamp should be cleaned while hot, as the filament is then stronger than when cold. It is also advisable to control the lamp from switches, thus avoiding the jarring caused by turning on at the socket. It has been customary to burn the lamp with the filament hanging downward in a vertical direction this being necessitated by the sagging of the filament, but lamps are now made to burn with the lamp hanging in any direction. The filament after having burned for some time shrinks considerably and this must be provided for in the manufacture.

With Tungsten lamps designed for use on low voltage, the filaments are made of a much shorter length and are less liable to breakage. This class of lamp may be burned in series on the ordinary circuits of 110 or 220 volts, or suitable transformers are now made so that on alternating current systems these low voltage lamps may be wired up in multiple.

The filaments of both tantalum and tungsten can often be welded when broken, by shaking the lamp when connected in circuit, until the broken ends come together. As this operation generally has the effect of shortening the filament and lessening its resistance it brings with it an increase in candlepower.

NITROGEN-FILLED LAMPS

The lately developed nitrogen-filled lamps have caused considerable comment by their extreme brilliancy and high efficiency. The larger sizes of these lamps operate at a considerable advantage over all other incandescent illuminants.

The intrinsic brilliancy is very high and they should preferably be hung high enough to be out of the range of vision; otherwise they will be injurious to the eye.

The temperature of the enclosing globes is very high, and if used out of doors where they may be struck by sleet or rain while hot they are likely to be broken.

It is best to use these lamps only in special sockets containing no material which may be affected by the heat, and where wires are run close enough to be affected by the heat the ordinary rubber-covered wire should not be used. Asbestos-covered wire is preferable.

The color value of these lamps is very good and they are well suited for color-matching and also for photographic work, although for the latter purpose they are not as fast as some types of arc lamps and the mercury vapor lamps.

The distribution of light from these lamps is quite uniform in nearly all directions and is emitted from a point source more nearly than that of any other lamp except the arc lamp. It will, therefore, throw strong shadows, and requires special reflectors.

The efficiency of the smaller lamps is not much better than that of the ordinary mazda, or tungsten, lamps, but the light is more concentrated and a

greater brilliancy is obtainable. This fact makes them very desirable for show-window lighting.

The following table gives approximate data concerning nitrogen-filled tungsten lamps:

Volts	Size of lamps in watts	Efficiency in watts, per c.	Amperes per lamp approx.
105	400	.75	3½
to	500	.70	4½
125	750	.60	6½
	1000	.55	8½

ILLUMINATION

Light, so far as its practical use is concerned, depends upon its value as a means of discrimination both as to form and color. The amount of light which is useful for this purpose is known as the illumination, and depends upon the quality and strength of the light giving source, and its distance from the object to be illuminated.

The unit of illumination is the candle foot, being the amount of light received by a surface placed at a distance of one foot from a light of one standard candlepower. The illumination on any surface is in-

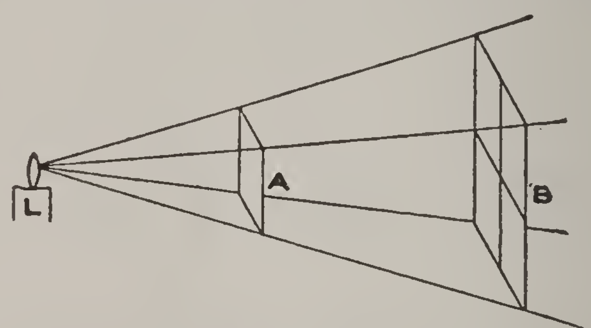


Figure 144

versely proportional to the square of its distance from the source of light. This is plainly shown in Figure 144. If the surface A is so located that all points on it are at a distance of one foot from the one candlepower light L, the intensity of the light on this surface will be one candle foot. The surface B, located at a distance of two feet from the light L is illuminated over a surface four times that of surface A and the illumination is, therefore, decreased to one-fourth; or in the inverse ratio of the square of the distances from the source of light.

A 16-candlepower lamp would produce an illumi-

nation of one candle foot on a surface located four feet away from the lamp, and this is considered sufficient for all ordinary purposes, but for brilliant illumination much greater intensities are often used. Table V gives, for different classes of lighting, the amount of illumination in candle feet and the corresponding area in square feet for each 16-candlepower lamp, to produce this illumination.

TABLE V.

		Square feet per lamp, lamps four feet above object.
Halls	1 to 3 candle feet	60 to 20
Reading	1 to 3 candle feet	60 to 20
Desk	2 to 4 candle feet	30 to 15
Book keeping	2 to 4 candle feet	30 to 15
Clothing stores	4 to 6 candle feet	15 to 10
Drafting, engraving	5 to 10 candle feet	12 to 6

In using this table the color of the walls must be taken into consideration. With dark walls, the greatest number of candle feet should be used.

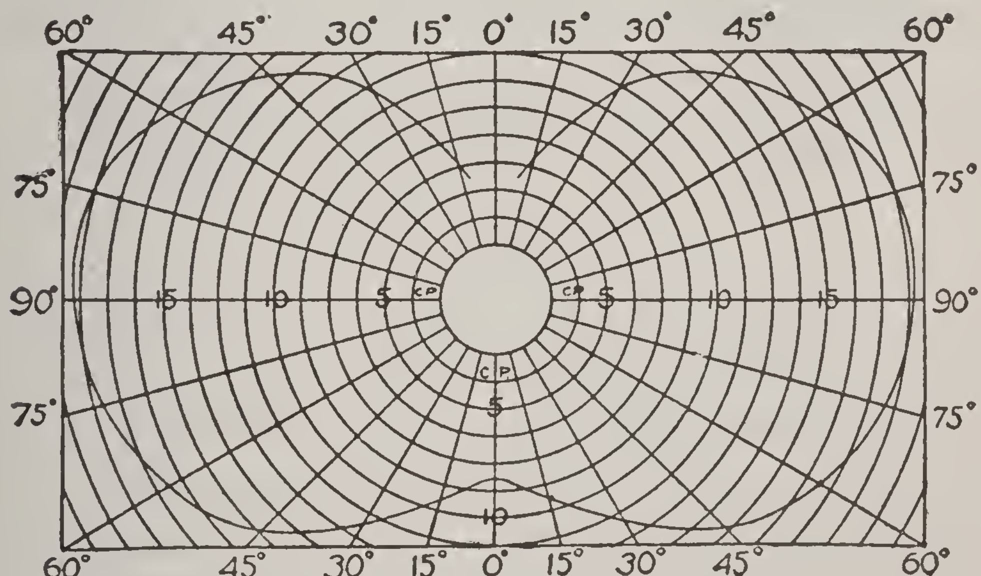


Figure 145

With an incandescent lamp the light is not given out uniformly in all directions. The distribution of

light from a 20-candlepower metallized filament lamp is shown in Figure 145, where the candlepower taken at various angles in a vertical plane are plotted. The concentric circles represent the candlepower marked on them

The curve of light distribution varies in the several types of lamps, and is greatly affected by the shape of the filament. It will be seen from the curve, Figure 145, that a considerable amount of light is given out

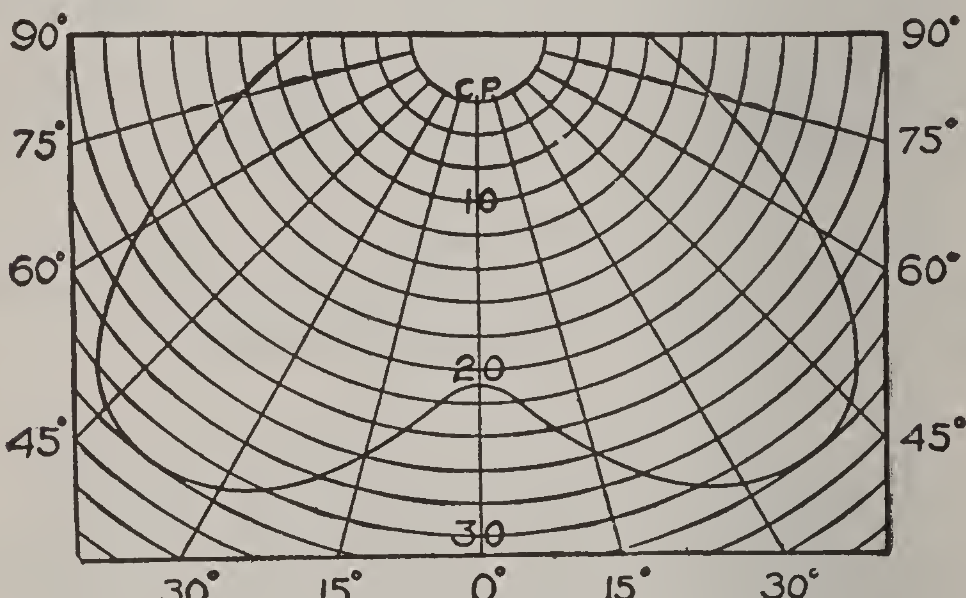


Figure 146

in a horizontal direction while, as a general rule, the greatest light is desired below the lamp. By the use of suitable reflectors almost any distribution of the light desired may be obtained and the effect, so far as the candlepower at points below the lamp is concerned, is clearly shown by the curve, Figure 146. Here the maximum light is given off at an angle of 40° and the lamp is much more useful for ordinary purposes.

The amount of illumination at any given point over an area will depend upon the candlepower of the lamp, the distance from the lamp and the angle that the surface makes with the line of the direction of the light. The first two factors have been explained and the last one will be readily understood from every day experience, it being well known that the greatest amount of illumination, in reading, for instance, is obtained when the paper or book is so held that the light strikes it at right angles. The curve, Figure 147, represents the illumination at various points at different distances from the source of light. If two similar lamps are placed 16 feet apart, the resultant illumina-

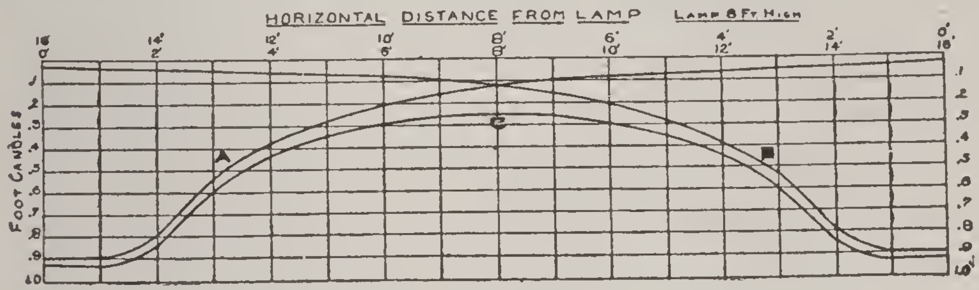


Figure 147

tion will be equal to the sum of the two curves A and B or as shown by curve C.

To lay out a curve of this kind it is necessary to know first the curve of the distribution of the particular lamp used. It is also necessary to know the proportion of light reflected at right angles to the surface, where the light strikes the surface at an angle.

That the color of the walls and ceiling of a room has a great effect on the amount of useful light is shown from Table VI, which gives the coefficient of reflection for various colors. As the light reflected from the walls and ceilings is but a small proportion

of the total light, the values shown are only useful in comparing the several wall colors. The size of the room and the use of reflectors will also greatly modify the effect of the wall coloring.

TABLE VI

Color of Wall.	Coefficient of Reflection
White paper	.70
Chrome yellow	.62
Orange paper	.50
Plain deal (clean)	.45
Yellow paper	.40
Yellow painted wall (clean)	.40
Light pink paper	.36
Plain deal (dirty)	.20
Yellow painted wall (dirty)	.20
Emerald Green Paper	.18
Dark brown paper	.13
Vermilion paper	.12
Blue green paper	.12
Cobalt blue paper	.12
Deep chocolate paper	.04

Good illumination requires that the light be of sufficient strength to plainly discern the object illuminated. The light must be uniform. A flickering or streaky light is very bad on the eyes. The light should not be exceedingly strong, as a strong light is very injurious to the eye; nor should the light be too dim, as the eye strain is considerably increased. The lights should always be so arranged that the direct rays of light do not fall on the eye.

CHAPTER XVII

NERNST LAMP

Figure 148 shows a diagram of the Nernst Lamp. The glower G (which emits the light) is composed of an oxide which when cold is of quite high resistance, but this resistance is lowered as the temperature rises.

When the switch is closed the current passes

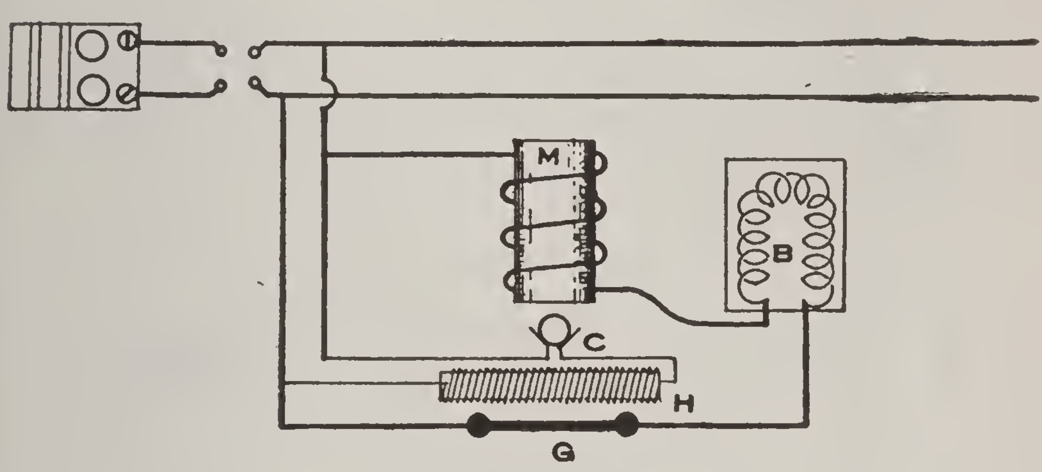


Figure 148

through the fine wire of the heater H which soon heats the glower so that current begins to flow through it. When this current attains approximately its normal value the magnet M attracts the cut-out C and in so doing opens the heater circuit and prevents further consumption of energy. B is a fine iron wire resistance which serves to steady the current. The resist-

ance of the iron wire increases as the current increases and thus exerts a steadying effect.

This lamp gives out a very serviceable white light and is of much higher efficiency than the ordinary carbon filament incandescent lamp. A glower that consumes about 88 watts is supposed to yield about 60 candlepower.

The starting current is always about 20 per cent in excess of the normal operating current.

These lamps can be had in a great variety of sizes, either for 110 or 220 volts, and for either direct or alternating current. On alternating currents the life of the lamp is, however, much longer than on direct current circuits.

As the glowers are always located at the bottom of the frame the distribution of the light is very good and reflectors are not needed.

COOPER-HEWITT LAMP

Figure 149 shows a diagram of the connections of the Cooper-Hewitt Lamp for direct currents. These lamps each contain a small quantity of mercury through which the current must be established for a short time and then broken. This is accomplished by tilting the tube slowly so that the mercury in it running from the high to the low side forms a continuous stream and allows the current to start. After the current is started the mercury continues to run to the low end and finally breaks the circuit; but the current now continues to flow and produces a greenish light of very high actinic quality. The lamp is extremely well suited for photographic purposes. Great care

must be exercised that the lamp is connected properly with reference to polarities. Current passing through it in the wrong direction will quickly ruin the lamp. The circuit can readily be traced in the figure. When the main switch is closed and before the lamps are tilted the current passes through the resistances R and the contacts M. When one of the lamps is tilted and current established through it the magnet is energized and attracts the armature M, thus cutting out the

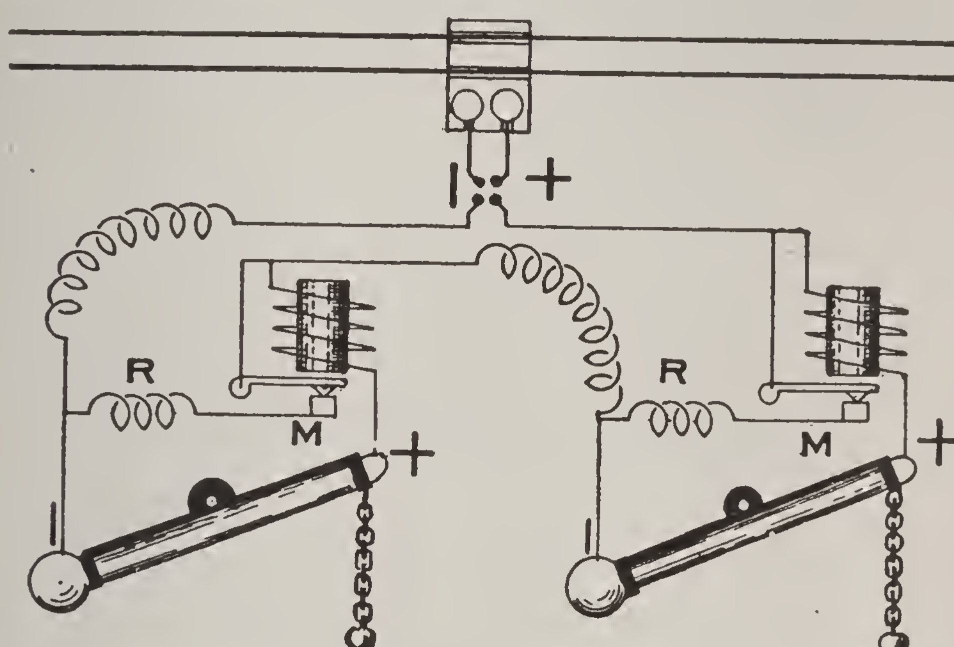


Figure 149

path through the small resistance in parallel with the lamp. Should one lamp fail to work, the current through the magnet would cease and the armature fall thus closing the circuit so that the other lamps may remain in use. The main switch should never be left closed while the lamps are not in use as current would be continuously flowing.

The lamps must not be used with the negative electrode tilted too high up.

The current should never be allowed to exceed 4 amperes and should normally not exceed 3½. The resistances R are adjustable and should be set for this current value.

These lamps are sometimes arranged to be started by a high induced E.M.F., an induction coil is arranged to send a momentary kick of current through the tube which starts the lamp. Sometimes, also, two lamps are mounted on one frame and started together. In such a case the shunt circuit around the lamps may be omitted. The life of the tubes is said to be about 1600 hours.

CHAPTER XVIII

INSTRUMENTS FOR TESTING

Probably the easiest and simplest way of testing is by "tasting." This is done by placing the two ends of the wire being tested on the tongue. The passage of current from one wire to the other over the tongue decomposes the saliva on the tongue and leaves a salty taste. This salty taste is an indication of current flowing. If there are several cells of battery connected to the line one wire may be held in the hand and the other placed on the tongue or, if one terminal of the batteries is grounded, a person standing on wet or moist ground can taste the current by placing one wire on the tongue.

Obviously this test is very limited, being used as a rule only in bell work to ascertain if current is obtainable at a certain point. Some care must be exercised, in using a test of this kind, not to allow the wires to come together on the tongue, as a considerable spark is obtained when a circuit containing magnets is broken.

Another test in which the chemical effect of the current may be used to determine both the presence of, and the direction of, flow of current consists in holding the two ends of wire being tested in a cup of water or

a solution of water and salt or water and acid. The presence of the current will be indicated by the formation of hydrogen bubbles on one of the terminals and owing to the fact that the bubbles form on the negative terminal the direction of flow of the current can be ascertained.

The chemical effect of the current is also made use of to determine the amount of current flowing. The Edison chemical meter, which is now almost out of use, consists of two plates of zinc suspended in a solution of water and acid and so connected to the main circuit as to allow a certain definite proportion of the main current to flow between the plates. The amount of zinc deposited on the negative plate measures the amount of current that has passed through the meter.

The heating effect of the electric current is sometimes made use of in testing, the mere fact of a conductor being hotter than the surrounding atmosphere generally indicating the presence of current and roughly the amount.

By making use of the magnetic properties of the current several more convenient and satisfactory methods of testing are available. Probably the simplest of any of these methods consists of the ordinary vibrating electric bell, such as is used for call bells, etc., or a telegraph instrument. The use of a telegraph instrument has some advantages over the bell in that it is more sensitive to small currents and, by varying the adjustment of the spring on the sounder the comparative strength of the current may be roughly determined.

One of the oldest testing instruments is the com-

pass. This in its simplest form consists of a piece of magnetized steel pivoted or suspended so that it can turn about its central point. The compass needle being magnetized sets up a field of force in which the lines of force emanate from the north pole, and encircling the needle enter at the south pole. As the earth itself is surrounded by lines of force extending from the north pole to the south pole, the compass needle being free to move tends to set itself in a north and south position. A wire carrying current is surrounded by a field of force as has been explained in previous chapters. When a compass is brought into the field of force the needle assumes a position due to the result-

Figure 150

ant field. By means of Ampere's rule, which is given below, the direction of the current flow can be easily determined.

Ampere's rule: If a person swims with the current and looks at a north seeking pole it will be deflected to the left. The relation existing between a wire carrying current in a certain direction and a compass needle held either above or below it is shown in Figure 150. The direction in which the needle tends to point is reversed by changing it from above to below the wire or vice versa.

The expansion of a wire due to the heating effect of the current flowing in it is made use of to indicate the

amount of current flow in the so-called "hot wire" instruments.

A wire of some length is rigidly fastened at one end, the other end being attached to a spring. A pointer is attached to the wire at the point where it and the spring connect On sending a current through the wire it becomes slightly heated and expands, the amount of expansion being indicated by the position of the pointer on a suitably graduated scale. Necessarily the resistance of the instrument is quite low. Instruments of this kind are "dead beat" and are unaffected by external fields. They can be used on either direct or alternating current.

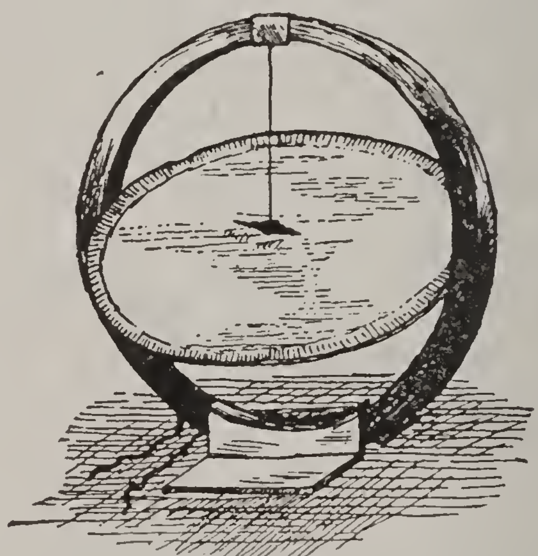


Figure 151

Practically all measuring instruments in use at the present time operate on the principle previously described in connection with the compass needle.

In Figure 151 is shown a tangent galvanometer. The wire is wound on the outside of the large ring and may consist of a number of turns of small wire or a few turns of large wire, or, as is sometimes the case,

two separate windings may be used, one of fine wire and one of large wire. In the center of the ring is placed a compass needle. The length of this needle is small as compared with the diameter of the ring so that whatever position it may assume, the needle is always in a practically uniform field. A light pointer attached to the needle moves over a graduated scale.

When the galvanometer is used it is placed in such a position that the coil lies parallel with the lines of force of the earth's field, i. e., points north and south. The current flowing in the coil is proportional to the tangent of the angle of deflection of the needle and it

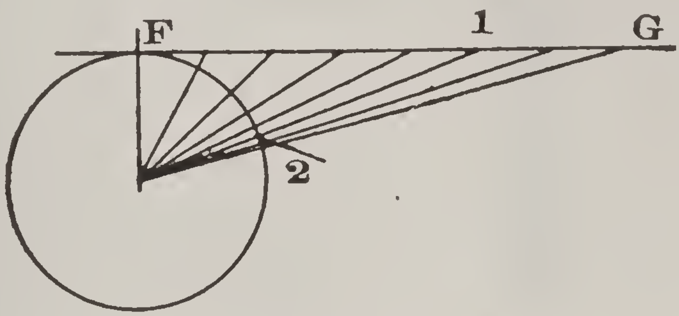


Figure 152

is from this fact that the instrument derives its name.

The meaning of the tangent is explained by Figure 152. The tangent of an angle is the length of the line from F to where a line drawn from the center of the circle through the angle in question intersects the line F G. Thus a current deflecting the needle to the point 2 on the circle is proportional to the length of the line F 1 and not to the space between F 2. This type of galvanometer is used only in the laboratory or testing room.

Where it is desired to measure very small currents, as where very high resistances are to be measured, a

galvanometer more sensitive than the tangent galvanometer must be used. The mirror galvanometer is often used for this purpose.

Figure 153 shows the principle of the D'Arsonval galvanometer. The field of this instrument consists of two permanent magnets between the poles of which is suspended a coil of fine wire. This coil is suspended

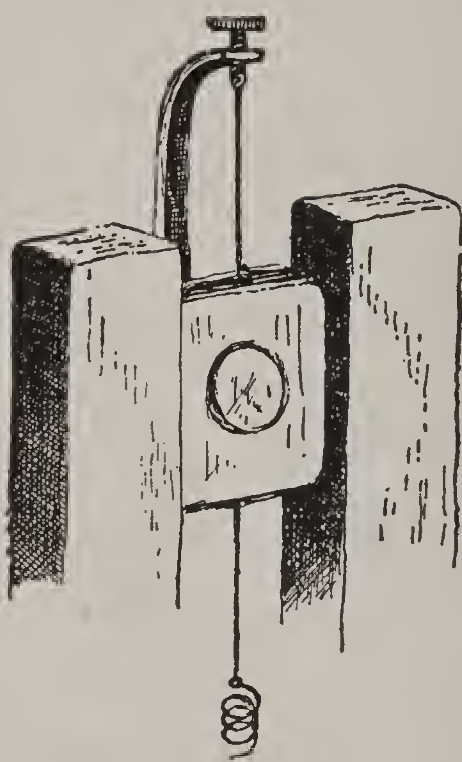


Figure 153

by a wire from the screw shown at the top of the instrument in the illustration. The current being measured passes down through this suspension wire, through the wire of the coil and out by means of a spiral spring which is connected to the lower end of the coil. A very light mirror attached to the movable coil serves as a means to determine the extent of the deflection. Either of two methods may be employed. A

lamp and a graduated scale are so arranged that a beam of light coming through a slit in a hood over the lamp falls on the mirror and is reflected on the scale. A telescope may be used in place of the lamp. The telescope is focused so that the scale is visible in the mirror. The slightest movement of the mirror can then be accurately read through the telescope.

Practically all of the instruments just described are made use of only in the laboratory and are not suitable for ordinary switchboard and testing purposes. To be of commercial use an instrument must not be seriously affected by the earth's magnetism nor by the presence of large masses of metal or strong magnetic fields such as are apt to be found in a dynamo room for instance. The instrument must be portable, and the accuracy of the indications must not change unduly with continued use. The instrument must also be easily read and unnecessary calculations avoided.

Commercial instruments are divided into three general classes, those for use on direct current, those for use on alternating current only, and those for use on either direct or alternating current. In each of these three classes instruments are designed for special purposes, such as the mesurement of voltages, measurement of current strength and measurement of electrical power. Although the principles upon which these various instruments operate are the same, still there are some differences in their construction depending on the purposes to which the instruments are to be put, as will be described further on.

Almost any of the galvanometers previously described could be used for the measurement of direct

current voltages, but, for the reasons already assigned, most of them are impracticable for general use.

In Figure 154 is shown the well known Weston instrument. A permanent magnet M, constructed of a specially prepared steel having the property of retaining its magnetism for an indefinite time, is fitted with soft iron pole pieces. In the space between the pole pieces, held in place by a non-magnetic metal such as brass, is a soft iron core. A coil of fine copper wire wound on a copper form is movable in the air gap between the inner core and the pole pieces. In order

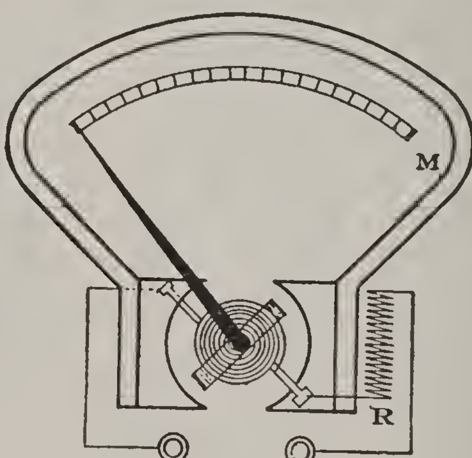


Figure 154

that the resistance to turning due to friction be reduced to a minimum the coil rests in jewel bearings. Two flat spiral springs, one above the coil and one below it, serve the double purpose of providing a torque against which the coil must act and also carry the current to the movable coil. A light pointer fastened to the shaft upon which the coil revolves moves over a scale graduated in divisions suitable to the purpose to which the instrument is put.

Copper wire being used in the winding of the coil some resistance must be connected in series with this

coil where the instrument is to be used, to measure comparatively high voltages. This resistance is usually inserted in the instrument and consists of a resistance wire having a very low temperature coefficient, or, in other words, a wire of such composition that its resistance will be but little affected by changes in its temperature. The importance of using a wire of this kind can readily be seen, for, should an instrument which had been calibrated at a temperature of 70° be used in a room at a temperature of about 100°, the decrease in current flowing through the instrument due to the increase in resistance in the heated wire would seriously affect the accuracy of the instrument.

The amount of resistance connected in series with the coil varies and depends on the voltages which it is intended the instrument should measure. In voltmeters for use on 500 and 600 volt circuits, this resistance is equal to about 65,000 or 75,000 ohms, thus allowing a current of about .007 ampere to pass through the instrument.

Current enters the instrument through the binding posts and passes through the resistance R, spiral springs and the coil. The magnetic field produced by the current flowing around the coil acts in conjunction with the field of the permanent magnet and tends to revolve the coil in a manner similar to that of the armature of a motor. As a matter of fact, this meter is simply a motor having a permanent field, and an armature that can make only a partial revolution. The amount of deflection will be proportional to the current flowing through the wire of the coil, and as the coil always moves in a practically uniform field a uni-

form scale will result. The movement of the coil is restrained by the spiral springs

This instrument is what is termed "dead beat," that is, the tendency of the pointer to swing backward and forward on deflection is reduced to a minimum. The movable coil is wound on a copper frame. When on deflection of the instrument this frame moves across the field of the permanent magnet, it cuts through lines of force and a current is produced in the closed circuit of the copper frame, this action tending to restrain the movement of the coil.

Figure 155 shows a type of instrument similar to the one just described but varying in some details. M

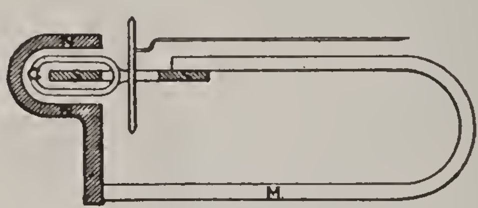


Figure 155

is a permanent magnet fitted with pole pieces of the shape shown in the figure, the pole S, S being shaped like an iron washer. A coil, C, is attached to a shaft which turns in jeweled bearings. A pointer attached to the shaft moves over a suitable scale. Current passing through the coil C causes it to revolve around the pole piece S, S. The instrument is made "dead beat" by the short circuiting of the copper frame on which the coil is wound.

A type of induction meter which is used only on alternating current circuits is shown in Figure 156. A copper or aluminum disc fastened to a shaft, rotates in jewel bearings. Projecting over the disc on one

side and so arranged that the disc rotates between its pole pieces is a laminated magnet C, on which is wound a coil of wire. Another coil C′ is placed so that its

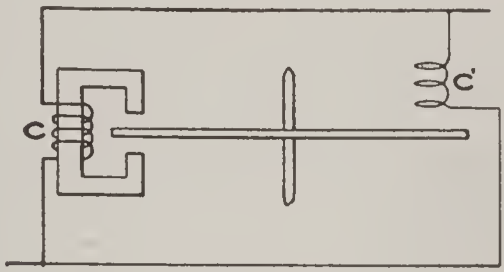


Figure 156

field cuts the disc. Both coils are connected in parallel. Owing to the fact that with an alternating current flowing through the instrument there will be a difference in phase in the current flowing in coil C and

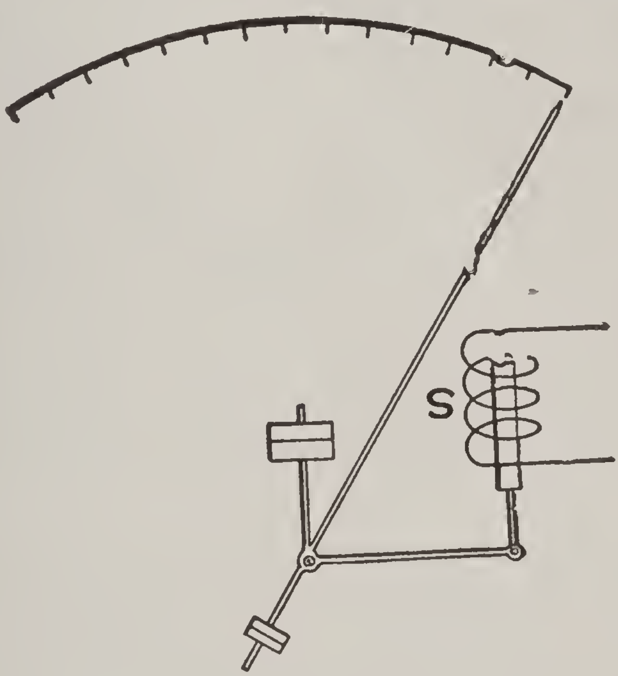


Figure 157

coil C′, coil C′ having no iron core, a torque is set up which tends to rotate the disc, the amount of deflection being indicated by the pointer attached to the shaft.

Figure 157 shows in a simplified form an instrument which can be used for the measurement of either direct or alternating currents. The current to be measured is carried through a solenoid S. In the center of the solenoid is suspended a soft iron core, which is free to move up or down, the motion of the core being registered by the pointer attached to the supporting arm. A counterweight serves to balance the iron core.

When current flows through the solenoid the iron core is drawn down into it, the amount of current flowing being indicated by the pointer.

The principle upon which this instrument operates is made use of in a number of different instruments. As the action of the solenoid is the same when either direct or alternating current is used, this instrument may be used on circuits of either system.

Instruments of the design just described have the objection that when used on direct current, with an increase in current strength, the instrument will indicate lower than it should, while with a decreasing current it will indicate higher. This is due to "hysterisis" in the iron core, and if the core contains any great quantity of iron, makes the instrument valueless as a voltmeter. With direct current more accurate results may be obtained by first increasing the current, then decreasing it and taking an average of the readings. On alternating current systems, this objection does not exist, but in this case the iron core must be laminated to avoid the generation of eddy currents.

The Weston instrument having a permanent magnet field cannot be used for alternating current meas-

urement. Figure 158 shows the construction of the instrument desiged for use on alternating current circuits. An outer coil C is wound on a circular form. Inside of this coil, mounted on jewel bearings, is a movable coil C′. Two spiral springs convey the current to the movable coil and restrain its motion. The two coils are connected in series. When current flows through the coils, the movable coil tends to take up a position parallel with the stationary coil. When used on alternating currents, the polarity of each coil reverses at the same time, so that the effect is the same

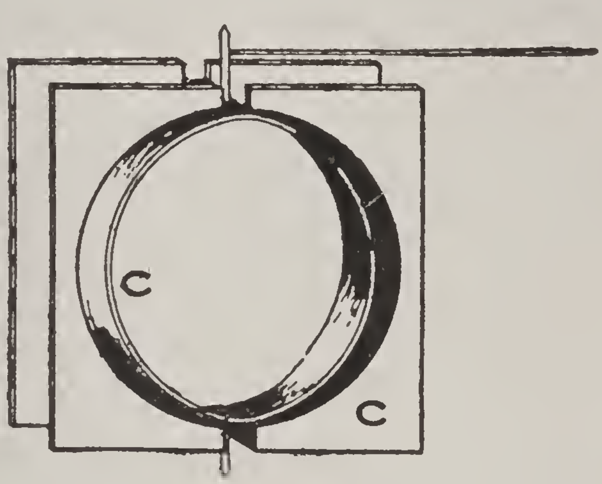


Figure 158

as though direct current was used. The instrument is damped by a metal vane moving in a partly closed air chamber.

The difference between a voltmeter and an ammeter is merely a difference in winding. A voltmeter is wound with a very fine wire and registers the difference in pressure between two wires. The finer the wire or the greater the number of turns, the more economical is the instrument in operation. It needs only to produce magnetism enough to deflect the pointer sufficient to admit of accurate calibration.

If in any circuit the pressure is greater than the range of any accessible meter, several of them may be connected in series and the readings of all of them added. It is also possible to measure the voltage between two wires in the manner shown in Figure 159. The voltmeter here measures the difference of potential around one lamp and if all lamps are exactly the same this need be but multiplied by the number of lamps in series to obtain the voltage over the whole group. If more accurate results are desired, the voltage around each lamp may be taken and all of them added. Should, however, the lamp at the voltmeter break

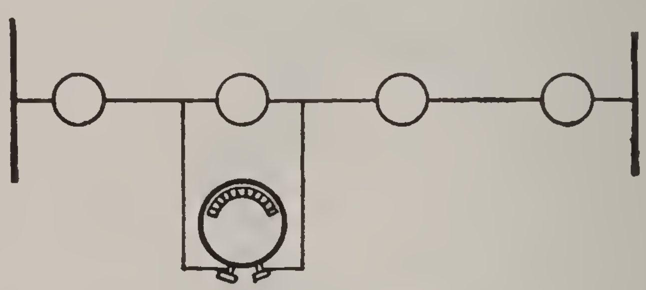


Figure 159

while the meter is connected around it, the voltmeter might be quickly burned out.

There are two classes of commercial ammeters. One of these, not extensively used, is cut in series with the line and all of the current passes through it. Such ammeters have very few turns of wire and are seldom used on heavy currents. The kind in most extensive use at present is known as the "shunt" ammeter. This type of ammeter takes only a small fraction of the current, the bulk of it passing through the "shunt." Such a shunt is shown in Figure 160 and the manner of attaching the cords leading to the ammeter is also shown. The shunt must be designed for

the particular instrument with which it is to work. Nothing must be allowed to disturb the relative resistance of shunt and instrument and the cord sent with them should always be used full length, or the readings will be inaccurate.

The measuring capacity of any ammeter may be increased by providing a suitable shunt. If the resistance of the shunt is made 1/9th that of the ammeter, the readings must be multiplied by 10 to obtain the flow of current, if 1/99th by 100, or 1/999th by 1000.

If the capacity of one ammeter is insufficient to measure the current, several of them may be con-

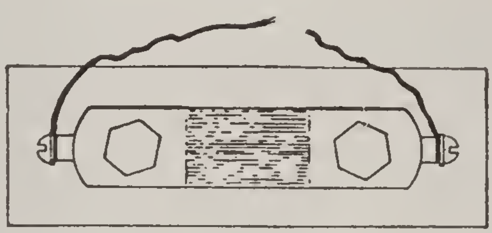


Figure 160

nected in parallel, but each must be provided with its own shunt.

Two ammeters must never be connected to one shunt.

WHEATSTONE BRIDGE

For the measurement of resistances ordinarily met with the Wheatstone bridge is generally used The principle of its operation, if thoroughly understood, will greatly assist in comprehending its uses.

In Figure 161, a battery is connected in series with a resistance AB. If the battery has a difference of potential of one volt, and AB has a resistance of 10 ohms (the balance of the circuit being considered as

having no resistance) a voltmeter connected across from A to B would indicate one volt difference of potential. If the voltmeter is connected between A and C, the resistance between A and C being 5 ohms, the voltmeter will show ½ volt. According to Ohm's law $E = IR$. I, the current, being constant, the voltage between any two points must be proportional to the resistance between these two points. If the resistance between A and D is one ohm, the voltmeter connected between A and D would indicate 1/10 volt, while if the voltmeter was connected between B and D it would indicate 9/10 volt. The resistance of the wire A B

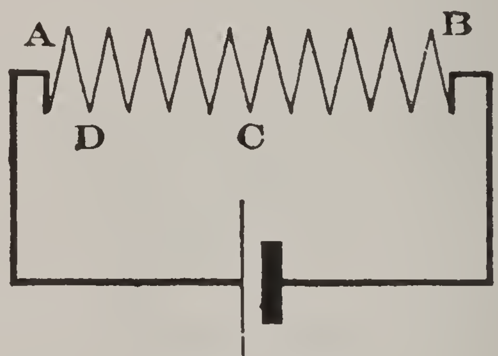


Figure 161

might be 20 or 30 ohms, or the battery might have a voltage of 10 or 20 volts, the drop over any two points on the resistance would, nevertheless, be proportional to their resistances.

In Figure 162, two resistances are connected in parallel with each other, and in series with the battery. If the voltage of the battery is one volt, that difference of potential will be shown by a voltmeter connected across A and B. The difference of potential between A and any point in the resistance A C B will be proportional to the resistance over which the voltage is measured. The same is true of resistance A D B so

that for every point in wire A C B there is a corresponding point in resistance A D B of the same difference of potential. Suppose C and D to be two points of equal potential, then there would be no current flow over a wire connecting these two points, and a galvanometer placed in this wire would indicate nothing. The resistance of A C will then be to the resistance of B C as the resistance of A D is to the resistance of D B. or calling these resistances b, x, a and r respect-

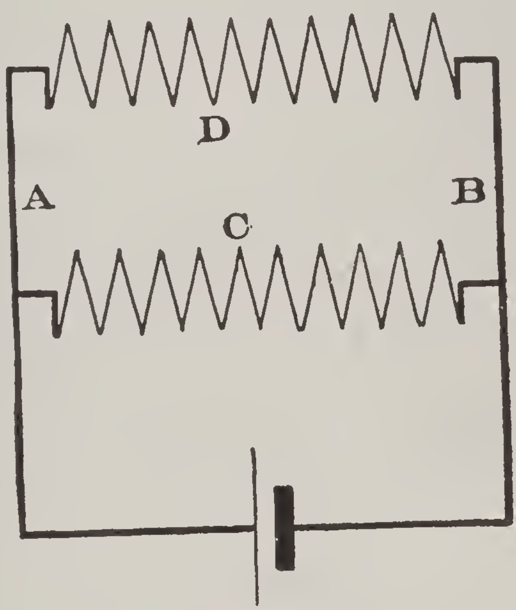


Figure 162

ively we have the proportion $a \div r = b \div x$. This expression may be written

$$\frac{a}{r} = \frac{b}{x}, \text{ then } x = \frac{b}{a} r$$

A diagram of the connections of the Wheatstone bridge is shown in Figure 163, a and b are the proportional arms, while r is the known resistance and x the unknown, or the resistance to be measured. The battery is connected across A and B while the galva-

nometer is connected between C and D. Both battery and galvanometer circuits are provided with keys and are normally open.

In the type of bridge shown, the resistances are connected between brass strips, brass plugs inserted in the holes between the strips short circuiting those resistances which are not used. In each of the proportional arms a and b one plug is always left out.

To measure an unknown resistance, proceed as follows: Connect the resistance to be measured across the terminals at X. Leave unplugged one resistance

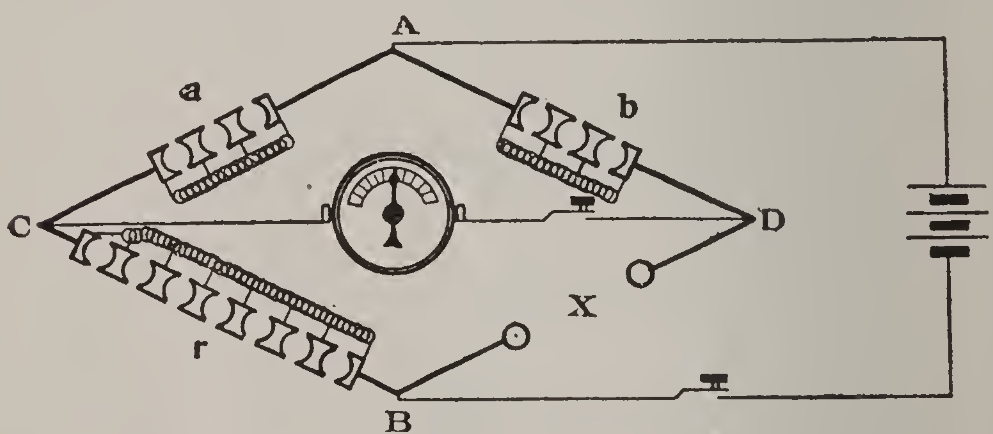


Figure 163

in each of the arms a and b. If it is known that the resistance of the apparatus being measured is not less than the smallest resistance in r or greater than the greatest resistance in r, make the unplugged holes in a and b of equal resistance, say 10 and 10, and remove one of the plugs in the arm r. Now press down the battery key and then the galvanometer key and note the direction of the deflection of the galvanometer needle. Now either replace or remove some of the plugs in r and proceed as before, and note the deflection. If the deflection is in the opposite direction the

value of the unknown resistance must lay somewhere between these two, and if the deflection is in the same direction as before, note the extent of the deflection, if greater too much resistance has been plugged in and if less, too little. Repeat these operations until no deflection is obtained. The total amount of the unplugged resistance in r will then be equal to the resistance being measured, for

$$x = \frac{b}{a} r, \text{ where } \frac{b}{a} = \frac{10}{10} 1$$

If the resistance or the apparatus being measured is such as not to come within the limits of the resistance in arm r, the unplugged resistance in one of the proportional arms a and b must be varied. If x is large as compared with r, then from the formula $x = \frac{b}{a} r$ we see that b must be made greater than a. If 10 ohms is unplugged in the a arm and 100 ohms in the b arm, then the unknown resistance x will be 100/10, or ten times the resistance in r. On the other hand, if x is small as compared with r, then $\frac{b}{a}$ must be small. With ten ohms unplugged in b and 100 ohms in a, x would be 10/100, or 1/10 of r.

When balance is obtained, the position of the battery and galvanometer could be reversed without changing

the indication of the galvanometer. In using the bridge the battery key should always be depressed first, for in measuring a resistance containing inductance or capacity such as a long lead covered cable or a circuit containing magnets, if the galvanometer key is depressed first and the battery key afterward, a deflection might be obtained on the galvanometer even with the resistances balanced, this being due to the

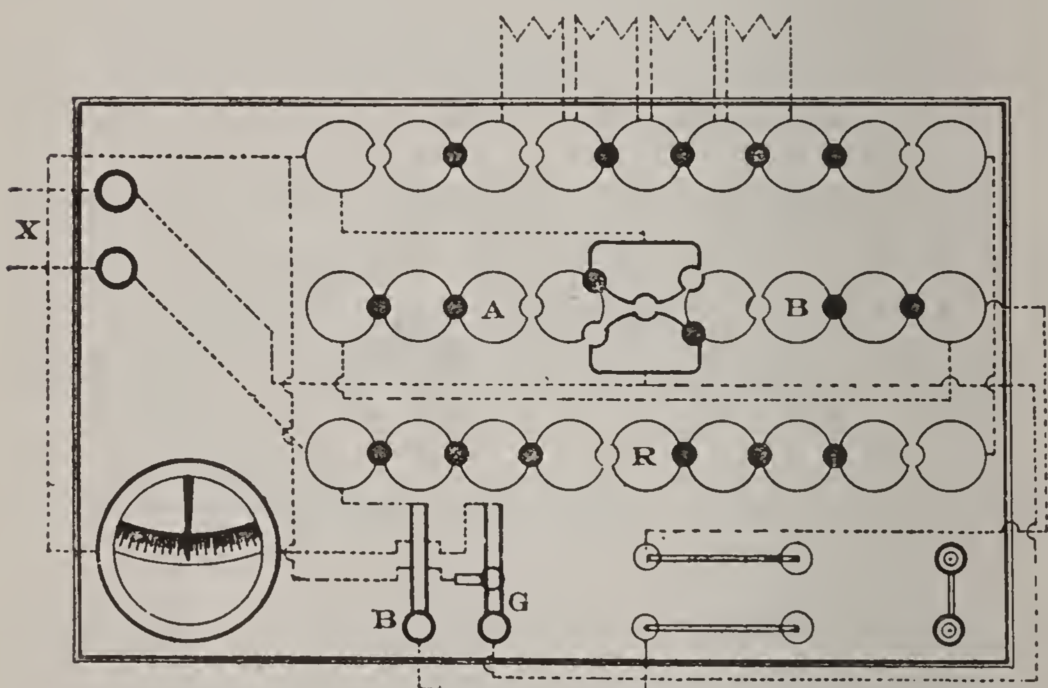


Figure 164

fact that inductance or capacity in the circuit tend to momentarily hold back the current so that it requires some time to come to its full value.

One form of Wheatstone bridge known as the Queen Acme testing set, which is in very common use, is shown in Figure 164 with a diagram of connections shown in Figure 165. A galvanometer and battery form a part of this set so that the instrument is complete in itself. A number of round brass blocks

mounted on a hard rubber base form the terminals of the various resistance coils, as shown in Figure 164. Brass plugs inserted in the openings between these blocks short circuit the resistance coils so that only those coils are in use on which the plugs are removed. The middle row of blocks form the two proportional arms corresponding to A and B, Figure 165, while the upper and lower arms form the resistance R.

The resistance to be measured is connected between

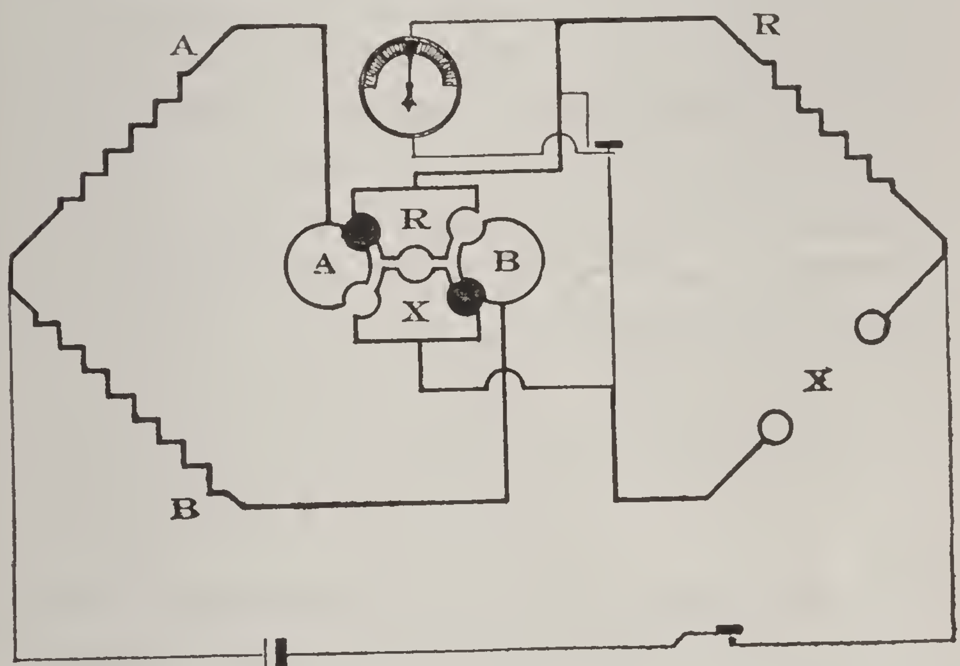


Figure 165

the posts marked X. The battery circuit is normally open, being closed by the key B. The galvanometer key is also normally open, being closed by the key marked G. When this latter key is released it makes contact with the point shown above the key, this short-circuiting the galvanometer winding. This action tends to stop the swinging of the needle and makes it come to rest quickly. Six chloride of silver cells are provided in a sealed metal case. Connection is made

to the cells by means of small plugs fitting over pins which are connected to the separate cells. By this means the battery strength can be varied for various tests.

The galvanometer is of the permanent magnet type, having a movable coil.

One particular feature of this bridge is the method of reversing the proportional arms A and B. This is more clearly shown by reference to the diagram, Figure 165, which shows a simplified diagram of the connections of the bridge. The two proportional arms are provided with different resistances, A having 1, 10, and 100, while B has 10, 100, and 1,000. With the plugs inserted between A and R and B and X arm A is placed in series with R and arm B with X. The resistance of X will now be

$$X = \frac{B}{A} R$$

With the plugs placed in the other two holes, between R and B and A and X the above arrangement is reversed or

$$X = \frac{A}{B} R$$

With the lowest resistance in A, 1 ohm, and the highest resistance in B, 1000 ohms X will be 1000 times R for the first positon and 1/1000 of R for the second position, so that for measurement of high resistances the plugs should be placed as shown in the

diagram, while for measurement of low resistances the plugs should be placed in the opposite holes. With a single plug inserted between R and X, the instrument may be used as a straight resistance box, the connection being made between the posts X.

MAGNETO

The magneto is used for testing purposes where an approximate determination of the insulation resistance or a test as to continuity of a conductor is desired. This piece of apparatus is a simple form of alternating current dynamo. The fields are formed by permanent steel magnets, while the armature is made of soft iron, the wires being wound through two slots running parallel with the axle. The armature winding consists of one coil of a considerable number of turns of fine wire. One end of this coil is directly connected to the metal frame of the magneto, while the other end is connected to an insulated pin running through one end of the shaft.

By means of a crank connected to a gear wheel working in a pinion on the end of the armature shaft, the armature is turned at a high speed. As the armature revolves an alternating current is generated flowing in one direction during half a revolution of the armature and in the reverse direction during the balance of the revolution

A polarized bell is connected in series with the magneto armature. A ring may be obtained with the ordinary testing magneto through a resistance of from 25,000 to 50,000 ohms, the capacity of the magneto depending on the strength of the permanent magnet,

number of turns of wire on the armature and the speed at which the armature is revolved.

In testing lead covered wires or cables, a ring is sometimes obtained even when the line which is under test is clear. This effect is due to the lead covering of the cable which causes it to act as a condenser, becoming charged as current from the magneto flows into the wire and then discharges back through the bell magnets. The same effect may be produced in testing lines installed in iron pipe. In this case the action is as follows: When current from the magneto flows into the wire lines of force are produced in the space around the wire, these lines of force being greatly increased by the presence of the iron pipe. As the current ceases to flow into the pipe these lines of force close in on the wire and produce a current in the opposite direction to the original current.

These effects are generally obtained on long runs of wire only so that for the ordinary test the magneto will indicate correctly.

TELEPHONE RECEIVER

One of the most convenient devices for ordinary testing purposes consists of a telephone receiver connected in series with a few cells of dry battery. An outfit of this kind is easy to make, and has the advantage of being small and easy to carry about. The outfit generally consists of what is known as a "watch case" receiver connected to two small cells of dry battery. Flexible cords of suitable length are provided with clips at the ends. A permanent connection can be made with one terminal and the other used for

testing. The outfit is very light and can be easily carried in the pocket.

This apparatus has several advantages over the magneto. A test can be made in much less time as the necessity of turning the magneto is avoided. The telephone receiver being more sensitive than the magneto bell, the approximate resistance can be more readily ascertained. In fact, with a little practice one may become so accustomed to the "click" as to be able to determine very closely the insulation resistance. In using the apparatus in this way, contact should be made by simply "tapping" the wire which is being tested. The connection should never be left on for any great length of time, as the battery will weaken and the click will be reduced.

In testing for insulation resistance with a magneto, or in fact, any of the common methods in use for this purpose, the condition of perfect insulation is shown by no indication on the testing apparatus; for instance, no ring with the magneto. The same indication would be obtained if the apparatus was defective, or if the wires connected to the apparatus were broken so that one is never certain when no ring is obtained on the magneto bell that the wire being tested is clear.

With the battery and receiver a click will be obtained on nearly all tests, even though the insulation resistance is very high so that one can always be sure that the apparatus is working properly.

In testing a lead covered cable or wires in conduit, the condenser effect due to the lead covering will cause a click even where the wire which is being tested is

clear. This may be overcome by making a succession of contacts, the first contacts charging the lead covering and the succeeding contacts indicating the condition of the wire.

In making up an apparatus of this kind, it is well to have some means of opening the battery circuit when not in use, so that the battery will not short in case the ends of the flexible cords should come together.

CHAPTER XIX

TESTING DYNAMOS AND MOTORS

The usual tests to be made on dynamos are:

Insulation resistance.

Rise of temperature.

Regulation.

Efficiency.

The insulation resistance is easily measured by a voltmeter attached to a circuit, as shown in Figure 166.

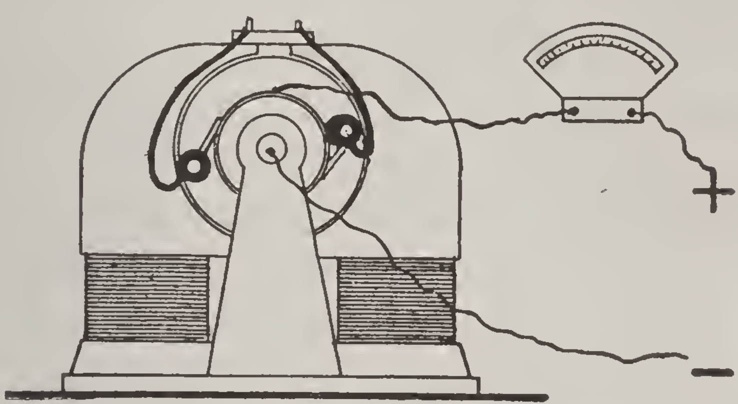


Figure 166

If there is any indication of current, the insulation is defective. The voltage used for this test should be equal to that for which the dynamo is intended. Very often such an indication is due to dampness and the machine may be cleared up by running it for a while with a strong current that will cause the wiring to heat up considerably. This must not be attempted if the voltmeter indicates a serious defect.

The formula for use in connection with a voltmeter when the exact amount of the resistance is desired to be known, is:

$$X = R \frac{V - V'}{V}$$

Where V is the full voltage of battery or other source of current and V′ the reduced reading obtained through the voltmeter and the resistance to be measured, and R the resistance of the voltmeter.

To determine the temperature rise, the machine must be run for some time with the full current for which it is designed. Small machines often attain their maximum temperature in five or six hours, larger ones must be run longer. It is always advisable to continue the test as long as there is any noticeable increase in temperature from time to time The test is made by placing a suitable thermometer upon the frame of the machine and covering it with waste so as to eliminate the cooling influence of the air. As an undue rise of temperature causes the most harm to the windings, it is to these that the thermometer should be applied and in such a location that the highest temperature produced in any accessible place will be recorded.

Roughly a temperature rise of about 60 degrees above the surrounding atmosphere may be allowed but if the machine is to operate in a very hot room, a lesser allowance must be made. Very few insulations will stand a temperature higher than 150.

To test the regulation of a machine it should be

run with loads varying from 0 to the full load. The greater the drop in voltage within these limits, the poorer is the regulation of the machine. If a compound wound machine is to be tested in this manner, the compound winding must be short circuited so that it will have no effect upon the voltage. After the foregoing test has been made, the compound winding may be placed in service and another test made to determine the regulation with this winding in action.

While this test is being made the action of the commutator may also be noted. A change in load, of course, brings with it a necessary change in the position of the brushes. This should not be very much, however, as the machine will be troublesome to handle.

The regulation test with motors is simply a test for variation in speed with changes in load. The load may be placed upon the motor by means of the Prony brake arrangement, shown in Figure 168, or by arranging to have the motor drive a dynamo as illustrated in Figure 167. In this test the change in voltage of the line supplying power should be taken into consideration. If there is much resistance in this line there will be considerable drop in voltage and this will cause a slackening off in speed.

A well designed shunt motor at the terminals of which a constant E.M.F. is maintained should not drop off more than 10 per cent in speed from no load to full load.

Figure 167 shows the connections for testing dynamos and motors without the expenditure of much energy. The motor M drives the generator G and the

current from it is pumped back into the line. The actual energy absorbed and lost in the test is only that which is taken up to overcome the friction and the losses in the two machines. This arrangement for obtaining a load can be used for any of the tests previ-

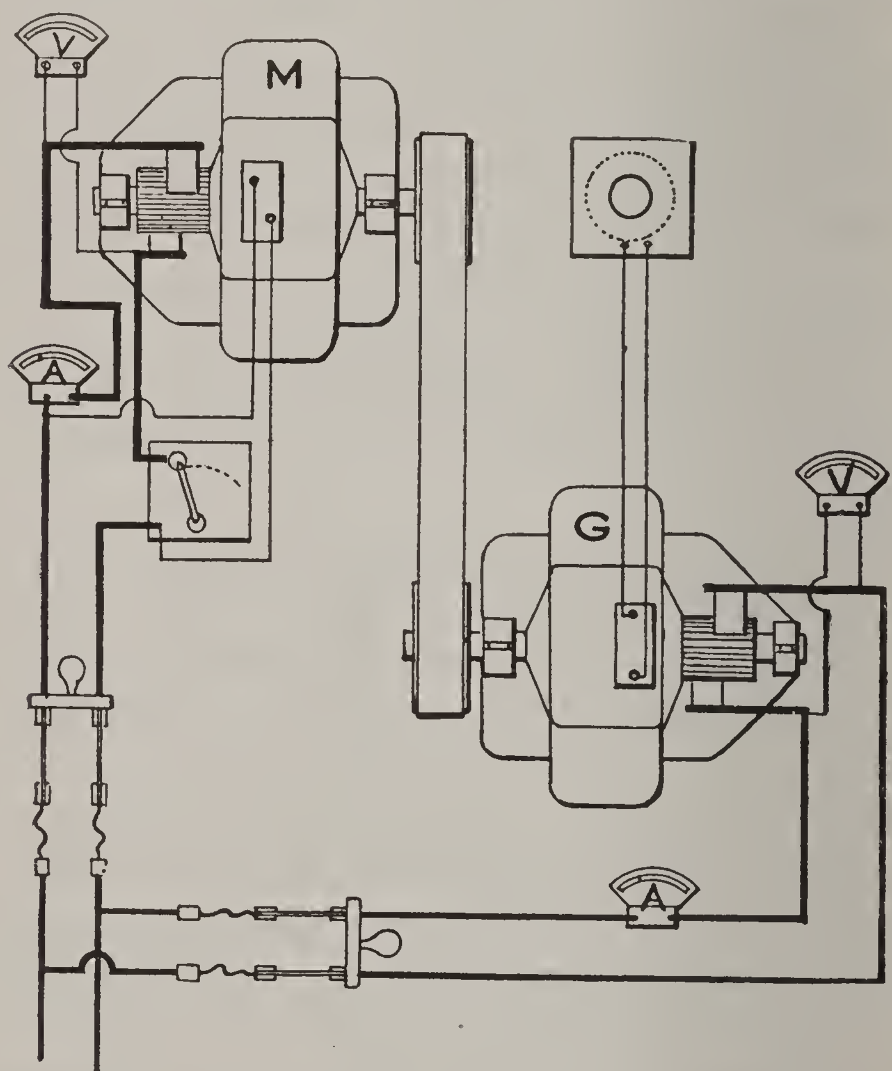


Figure 167

ously described. The power consumed by the two is found by multiplying the volts and amperes used by the motor.

The power delivered back to the line is equal to the product of the volts and amperes in the generator cir-

cuit. Roughly the efficiency of the two is the load on the dynamo divided by the power delivered to the motor.

In order to obtain the efficiency of the generator, we must first have the efficiency of the motor. If the two machines are similar, either motors or generators it will probably be accurate enough to assume that half the loss occurs in each machine.

If such is the case, we must take the square root of the combined efficiency to obtain the efficiency of the

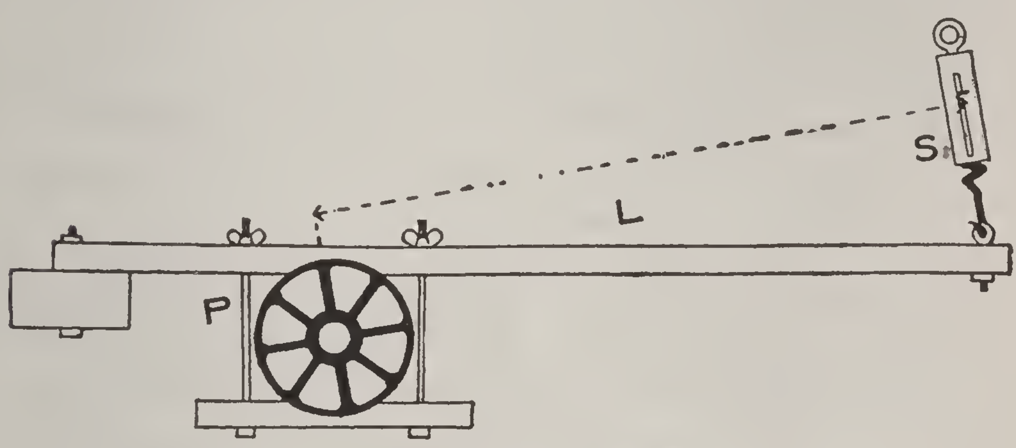


Figure 168

single machines. Thus, if the efficiency of the two machines is .81, the efficiency of either machine singly will be .90.

The efficiency of a motor may be tested by means of the well known Prony brake shown in Figure 168. In this figure P is a pulley attached to the shaft of the motor. The lever L is fastened to the pulley by means of the block and the thumb screws. When the motor is in motion the screws must be so tightened that they will allow of rotation of the armature shaft sufficient so that the motor may be taking the current at which it is to be tested. The spring scales

are provided to measure the force with which the motor acts upon the lever.

In order to learn the power delivered by the motor we must know the length of the lever from the center of the pulley to the scale. The number of pounds registered on the scales and the speed of the pulley in revolutions per minute. The product of these factors divided by 33,000 will give us the H. P. delivered by the motor.

The products of the volts and amperes maintained at the terminals of the motor while the foregoing observations were made will give us the H. P. consumed by the motor and the H. P. delivered divided by the H. P. consumed will give us the efficiency of the motor.

In connection with alternating current motors the volts and amperes at the terminals of the motor must be multiplied by the power factor. The power factor, however, varies with the load on the motor and other line conditions and will generally have to be guessed at unless a power factor indicator is at hand.

The above test is usually made at full load. If the losses at no load are required we need but take the produce of the volts and amperes when the motor is running empty.

The loss in the fields of a dynamo or motor may be made exceedingly small or may take up nearly the whole output of the machine. From time to time cheap motors are brought out that require almost as much energy to excite their fields as is required to do the work. A test of the field losses can readily be made by measuring the current flowing in them. This

should not be much over 5 per cent of the capacity of the motor for medium sizes.

CIRCUIT TESTING

Figure 169 can be used to illustrate the principles which underlie the testing for trouble on series arc or incandescent circuits. The principal troubles encountered on such circuits are due, either to an open circuit, or to one or more grounds. If more than one ground exists and if those grounds are "good," they will cut out a number of lamps and for that part of the circuit amount to the same thing as though a short circuit existed on a multiple circuit. If, for instance, two good grounds exist as shown at B and C, they will have the effect of cutting out the lamps shown at the right, the current passing through the low resistance of the ground rather than through the lamps.

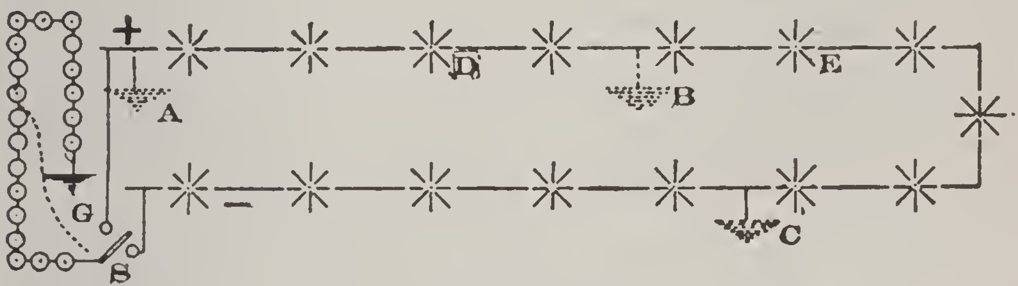


Figure 169

Sometimes, however, such grounds are not very good and then they merely rob the lights of part of the current; at other times such grounds are intermittent and due to wires swinging against wet trees or buildings, or the jarring of railroads, etc., which cause bare parts of the wires to come in contact with

grounded parts of structures. So long as there is but one ground on a system no harm can result because this can establish no circuit through which current can flow. But when the second ground appears, there is sure to be trouble, and furthermore the existence of one ground makes the appearance of a second far more likely because the resistance from pole to pole through the ground is thereby reduced one-half.

If one ground exists, the repair man or operator, if in connection with the ground will, when he touches the wire, at once establish the second ground and cause more or less current flow through his body. It is, therefore, of the utmost importance from every point of view to detect grounds as soon as they come on to a system. For this purpose every plant should be equipped with a ground detector as elsewhere described and frequent tests should be made with it.

If a ground has been noted on the line, the best way to locate it is the following: Cut off the current, leave the circuit open, and place a temporary ground on one of the wires at the station; then go out along the line and at some convenient place open the circuit of that wire on which the temporary ground is placed. Insert into the circuit any of the testing instruments previously described. So long as an indication is obtained it shows that you have cut into the circuit between the two grounds; when no further indication can be obtained the ground has been passed; thus, suppose the ground to be located is at B, Figure 169, and the temporary ground at A; if the testing set is introduced at D, there will be an indication of current,

while when it is placed at E there can be none. If the line has been closely watched, it is very unlikely that more than one ground will come on suddenly but in case of an old line that has been neglected and in the event of a heavy rainstorm, it may be possible that several grounds appear together. If the conditions make this appear as likely, it will be well to cut the line into sections and see which parts are clear as the above test will be very confusing if more than one ground should exist at the same time.

If the line cannot be cut dead long enough to locate the ground, there are two ways in which the ground can be located. One method which may be used if the ground on the line is good and if there is no danger from fire, consists in putting a second ground onto the system and noting which lamps are thereby cut out of the circuit. Thus, if as in Figure 169 the ground to be located exists at B and a test ground is put on at A, all of the lamps between A and B will be cut out and will show that the ground is somewhere between the two lamps, on either side of B.

In place of the foregoing, connections may be made as shown in Figure 169, at the left. Here the little circles represent a series of 100-volt incandescent lamps (each lamp requires twice the voltage of one of the arcs), which by means of the throw over switch S may be connected to either side of the circuit. G is a ground permanently connected at the last lamp in the series. These lamps as connected virtually measure the difference of potential which exists between the point on the line at which the ground is located and the location of the ground at the lamps. If, with

a ground located at B, connection is made by the throw over switch to the positive wire, there will be only the difference of potential due to four lamps which will cause the incandescent lights to burn, while if connection is made to the negative wire there will be a difference of potential equal to eleven arc lamps which will manifest itself on the incandescent lights. By means of the flexible wire shown in dotted lines, some of the lamps can be cut out until those remaining in circuit burn at full candlepower. If the voltage of the incandescent lamps is as indicated above, twice that of the arcs, then for every incandescent lamp burning at its proper candlepower, there will be two arc lamps between the station ground and the one on the line; in the case as shown in diagram, if connection is made to the upper wire, two incandescent lamps will burn properly while with connections made to the lower wire, five will burn.

To locate open circuits it is also of advantage to place a ground on one side of the line, at the station as at A. Now go out on the line and test back to this ground, of course, grounding the instrument you have. As long as you are located between the open place and the station, you will get an indication; when this place is passed no further indication can be obtained.

In connecting up arc lamps, it is best to begin at one end of the circuit, determine whether this is to be positive or negative, and connect the first lamp accordingly. Now ground that end of the circuit and proceed to the next lamp on that leg. If the wires are run overhead, there will be no difficulty in tracing the wires, but if they are underground there will be two

ends visible, and it must be determined which of these is to go to the positive and negative poles of the lamp. By grounding the end from which the start was made it will be easy to test back and find the leg which comes from the lamp first connected.

The finding of grounds on multiple circuits is a much simpler matter. Such systems are always subdivided into branch circuits so that no great amount of wiring is ever dependent upon a single fuse, and by these fuses any part of the wiring can be readily separated from the rest. A ground having been discovered on such a system, it becomes necessary to disconnect different centers until the one containing the ground is found. When so much is accomplished the branch circuits are next disconnected until the proper one is found. After this, if the wiring is open, an inspection will reveal the exact location, if the wiring is concealed it may further be necessary to disconnect parts of the circuit until at last the section containing the trouble is found.

With multiple circuits a broken wire always indicates very nearly its exact location, so that it can easily be found by inspection. If, for instance, in Figure 170, the wire is broken at E, the seven lights at the right will not burn, while those at the left will not be interfered with; if only the wire at F is broken only one light will be out.

A new system of incandescent lighting is best tested circuit by circuit. By testing for ground over a whole installation at once, there is always the chance that some of the fuses may not make proper connection (especially with cartridge and plug fuses) there

is also a likelihood that some of the switches may be left open; either of these conditions would make the test very unreliable. When each circuit is tested by itself the testing instrument can be connected to the binding posts of the cut-out, or at any socket in the circuit, wherever it is most convenient to obtain a ground connection for the instrument. Unless lamps are installed in the sockets each leg must be separately tested, and if switches do not indicate whether on or off, the test should be made with the switch in two positions, one of which is sure to be on. With most snap switches it is, however, easy to determine by the

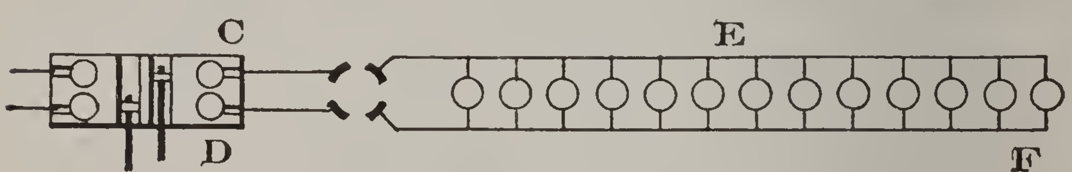


Figure 170

sound of the snap whether the switch is closed or open.

The next test to be made is for short circuit. If a good instrument is connected at C and D and a short circuit exists, it will at once cause an indication. If there is no such indication, we may proceed to test for continuity. For this purpose the testing instrument may be left at the cut-out and connection made at each socket with a screw driver or anything else by which the opposite poles can be brought together so as to obtain an indication on the test instrument. Where plug cut-outs are used, a lamp screwed into one of the receptacles of the cut-out is about the only test instrument needed except when testing for grounds.

In connection with three wire circuits, it is custom-

ary to run the neutral wire in the center, but one must not always rely upon this being the case. It is very important to have these wires properly connected, as a wrong connection will result very likely in the destruction of a large number of lamps, and possibly in causing a fire. If the neutral wire on the system is grounded there are two ways by which it can be found. The simplest method, requiring only one lamp, is to connect this lamp to ground and to the wires one by one, when connected to either of the outside wires the lamp will burn at full candlepower, while when connected to the neutral it will not burn at all. The other method requires two lamps but no ground connection, and on this account is the most used. Connect two incandescent lamps of the proper voltage in series and try the wires, two at a time; when the positive and negative wires are found, the lamps will burn brightly, while in connection with the neutral they will be at less than half candlepower. This test is also often made by touching the wires with the fingers where the voltage is not over 220 and determining by the severity of the shock which are the two outside and which the neutral wire.

If it is desired to learn which is the positive or negative wire, the test can be made by inserting ends of wire connected to the two poles of the circuit through some water contained in a small cup (non-conducting material preferred). The negative pole will be indicated by the formation of small bubbles of hydrogen gas near the wire. If a metal cup is used for this test, there is, of course, danger of a short circuit if the wires come in contact with the metal.

In Figure 171 we explain the testing out for the connection of a pair of three-way switches. It is assumed that the wires are run in conduit and nothing but the ends of the wires in the three junction boxes are visible. The switches are to be located at 1 and 2 and the lamp to be controlled by them at 3. First find which are the feed wires, in this case 4, and bend them out of the way; now at each of the switch outlets take any two of the three wires and twist the bared ends together and proceed to the light outlets, and by testing find the two short circuits thus made and permanently connect these two sets of wires together. Con-

Figure 171

nect the lamp to the remaining pair at this outlet and at 1 connect the single wire coming from 3 to one of the feed wires. The remaining feed wire now goes to that pole of the switch which is in direct connection with the line, and the other two are connected to the other binding posts. The other switch outlet is, of course, connected in the same way.

Figure 172 will help to illustrate the method of testing out a circuit of incandescent lighting for the purpose of making the final connections. We begin by placing some testing instrument and battery at the cut-out and connecting it to the circuit as at T. Now proceed to one of the outlets and baring the ends of wires found there, bring the different ends temporar-

ily together until two wires are found that cause an indication on the testing instrument. The most convenient instrument for this purpose is an ordinary call bell and battery, as it can be heard throughout different rooms. After the wires coming from the cut-out have been found, ends at other outlets may be temporarily connected together as, for example, at L and we now again try different wires in connection with the pair found until a ring is obtained which in-

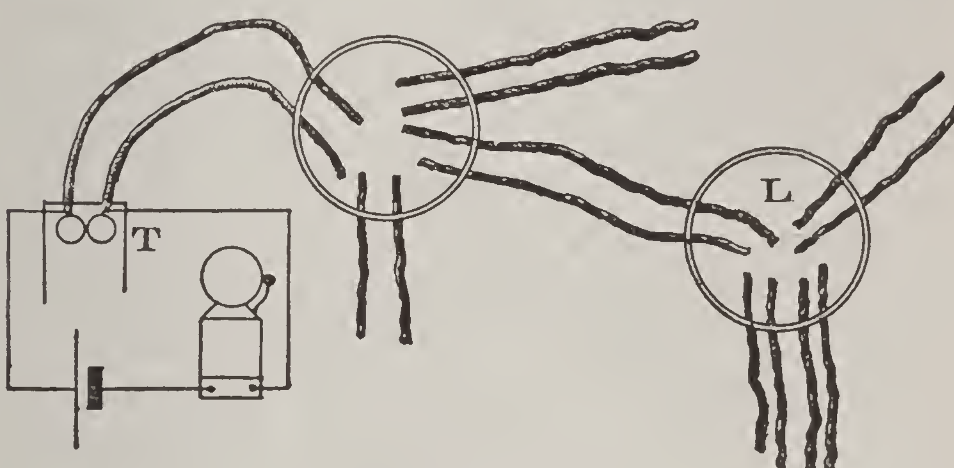


Figure 172

dicates that we have found the wires thus connected together. In this manner by proceeding from outlet to outlet the meaning of every wire can be determined and connections made as required. As a precaution, before beginning to test out in this manner, it will be well to separate all wire so there may be no accidental short circuits, which would cause confusion.

Three tests should be made on every fixture before it is installed, and for these tests sensitive instruments should be used, or a voltmeter and the pressure of the lighting system. The first test may be for short circuit in the wiring and for this purpose connections

are made as shown in Figure 173. If this test shows clear the connections may be left as they are and a test for continuity made by inserting a screw driver or other piece of metal into each socket so as to complete the circuit through the voltmeter and cause an indication. If all sockets are found perfect, the test for contact with the metal of the fixture may be made by disconnecting one of the wires, say 3, and bringing it in contact with the metal of the fixture while the

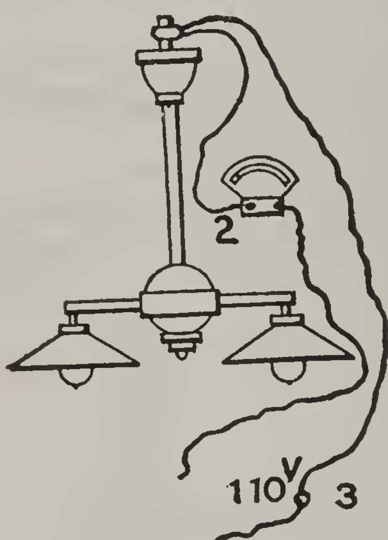


Figure 173

disconnected fixture wire is connected to the other wire of the voltmeter at 2.

A circuit can be tested for loss in the following manner: With a voltmeter measure the voltage at the supply end of the line, and also at the center of distribution or at the motor, as the case may be. The reading will always be greater at the supply end and the difference between the two will be the loss in voltage. In order to find the percentage of loss in the line, we divide the volts lost by the volts at the supply end.

The loss varies with the current and is inversely

proportional to it. In order, therefore, that the test may be of value, it must be arranged that at the time of test the average current be in use or if this is not practicable, the current flowing at the time of test must be known. The average loss will be in the same proportion to the loss indicated as the average current is to the current flowing at time of test. This current multiplied by the volts at the supply end of the line, will give the total watts delivered at this point, and this multiplied by the percentage of loss will give the total watts lost.

Instead of making the above test with a voltmeter, it can be calculated if the size of the wire used is known. The loss in voltage is equal to the current multiplied by the resistance, and, therefore, if the resistance is known, we need but multiply with the amperes to find the loss in volts. In the table below the loss in volts per 100 ampere feet (length of run, one leg, X current) is given to facilitate these calculations. The loss in volts is the same, no matter what the voltage of the system may be but, of course, the percentage of loss which the actual loss represents differs with the voltage of the system; thus, a loss of 5½ volts corresponds to a loss of 5 per cent at 110 volts, but only 2½ at 220.

B. S. gage.	Loss in volts per 100 amp. ft.
14	.53
12	.33
10	.21
8	.13
6	.08

4	.052
3	.04
2	.03
1	.026
0	.02
00	.016
000	.013
0000	.01

To find the loss in any line by the use of this table; multiply the current by the length of one leg of the line and divide by 100. Use the product so obtained to multiply the loss given in the table, the result will be the total loss in volts in the line.

If the size of wire in any installation is not known, the best and simplest manner wherever practicable to determine it is with a wire gage. Such a gage is, however, not always at hand and in connection with wires already installed, often cannot be used without cutting into the insulation.

Below is given a table by which the gage number of wires can be quite approximately determined from outside measurements. Although these measurements are not perfectly correct, they will not be found sufficiently inaccurate so that any very great errors will be caused thereby.

The circular mils contained in any wire can be found by multiplying the diameter of the wire expressed in thousands of an inch by itself. If the wire in question is stranded, the square of the diameter must be multiplied by .75, this will give quite approximate results although not quite accurate.

TABLE SHOWING OUTSIDE DIAMETERS OF WIRES IN 64ths

	Rubber Covered Wires.				Weatherproof Wires.	
	Single Braid.		Double Braid.			
B. & S.	Solid	Stranded	Solid	Stranded	Solid	Stranded
8	18-64	22-64	22-64	23-64	17-64	18-64
6	22-64	24-64	26-64	28-64	20-64	22-64
4	25-64	27-64	29-64	31-64	25-64	28-64
3	27-64	30-64	31-64	34-64	27-64	30-64
2	29-64	32-64	33-64	37-64	30-64	33-64
1	33-64	37-64	37-64	42-64	32-64	35-64
0	36-64	40-64	40-64	45-64	36-64	39-64
00	38-64	43-64	43-64	48-64	39-64	43-64
000	41-64	48-64	46-64	55-64	47-64	51-64
0000	47-64	52-64	54-64	57-64	50-64	55-64
250,000	.....	.....	.....	59-64	.....	58-64
300,000	.....	.....	.....	61-64	.....	62-64
400,000	.....	.....	.....	66-64	.....	73-64
500,000	.....	.....	.....	73-64	.....	80-64
600,000	.....	.....	.....	79-64	.....	85-64
700,000	.....	.....	.....	83-64	.....	94-64
800,000	.....	.....	.....	89-64	.....	100-64
900,000	.....	.....	.....	94-64	.....	103-64
1,000,000	.....	.....	.....	97-64	.....	108-64
1,250,000	.....	.....	.....	107-64	.....	.....
1.500,000	.....	.....	.....	113-64	.....	.....

TESTING FOR, AND PREVENTION OF ELECTROLYSIS

The damage due to currents of electricity passing from the grounded part of the structure and rails of any system of distribution, such as a street railway line for instance, depends entirely upon the relative resistance of the metallic return circuit afforded by the structure and whatever auxiliaries may have been

provided and the resistance of the earth in the vicinity of the structure.

There are but two ways in which this action can be lessened or prevented, the insulation of gas and water pipes being considered impracticable One of these methods consists in providing a metallic return circuit of very low resistance so that only a very small amount of current will escape from it. With this method the amount of copper required is large and varies with the conductivity of the earth return in different places. At best it can only mitigate the evil since no amount of copper can ever entirely prevent it.

The other method consists in bonding all pipes and other metallic bodies that are underground in the vicinity of the structure to the structure in such a way that current can pass to and from them without doing any damage. This latter method, of course, involves also the bonding of all pipes at all joints. If this is not done, it will aggravate the trouble rather than lessen it, since the various bonds might conduct a large quantity of current to a certain pipe which might be a very good conductor with exception of one joint, for instance, and at this joint the greater part of the current would pass from the pipe to earth and back again, thus rapidly causing serious damage. All of the damage occurs where the current leaves the pipes, and if it is not possible to make the piping a part of the return system as above described, the next best thing will be to protect those points where the current leaves the pipes.

To determine how this can best be done, comprehensive tests should be made. With a voltmeter which

will indicate the direction of the current, readings should be taken at a number of places, the more the better, from the structure or rails to accessible parts of gas and water pipes near the structure. The pressure and direction of current should be noted so that complete map of the system can be made from it. This being done, a map of the piping along the line of the railway should be provided, and the two combined in such a way as to show the exact relative position of pipes and leaks. In addition to this careful tests of the bonding of the structure should be made, and any bad spots marked upon the map. The map will now reveal quite approximately the relations existing between the structure and the earth, pipes, etc. The current flowing between structure and piping cannot be measured, but may be estimated.

If high pressure towards a pipe is found to exist and at the same time the pipe is very close to the rails, it would indicate a large current. The same pressure with the pipes farther away would suppose a smaller current. Again the high pressure might be caused by one or a few bad bonds. If the structure is perfect, and the pipe lines are also in about the same condition throughout the route, a maximum pressure from the rails to pipes will be found at the far end, and this will gradually decrease toward the middle and will from there on be in the opposite direction, from pipes to rails toward the power house. No attention need be paid to current passing from the rails. The endeavor must be to intercept the current where it leaves the pipes, especially where large currents are indicated. Unless the pipe line can be bonded through-

out, nothing that would lessen the resistance between structure and pipes should be installed, because this would increase the current. It would, therefore, seem to be advisable to connect suitable ground plates to the pipes where current leaves them, so that the electrolytic action would take place on these instead of on the pipes. If, however, the pipes are very close to the rails, the bonding to the structure would not affect the total resistance of the earth return much, and would, therefore, be preferable. In many places currents will be at different times found to be in different directions, so that all tests should be made to extend over some time.

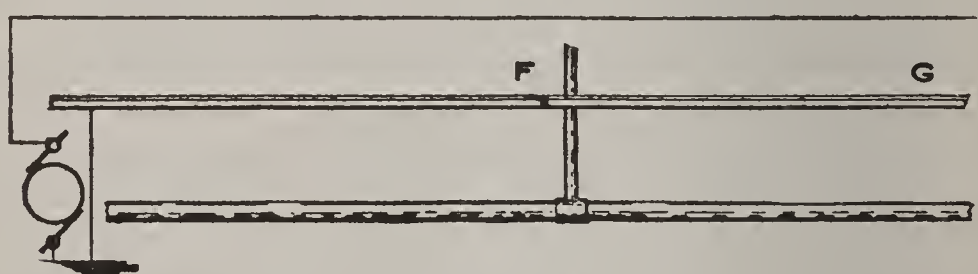


Figure 174

With conditions as shown in Figure 174, where the bad bond is indicated near the pipe, a train using current at G would cause current to flow from the rail to the pipe at the far end and from pipe to rail at the left of the bad bond. A train using current at F would cause a flow of current in the opposite direction. So long as the pipe is near the rails, it will always receive some current.

Tests should be made during that part of the day when the load is most evenly distributed. This will be at the busiest time. The pressure will vary with the currents used in the vicinity at time of testing. The

voltmeter used in testing is connected from the rails to the pipe. It is preferable to have a double scale voltmeter, which will also indicate the polarity, but this is not essential. If no reading is obtained at a certain place, with the wires connected one way, they may easily be reversed and the polarity noted on the map.

In Figure 175 a common method of testing bonds is illustrated. An ordinary milli-voltmeter is used and about 50 feet of No. 20 wire are inserted in each of the leads, as indicated in the diagram. This will give a resistance of about ½ ohm. The two wires nearest

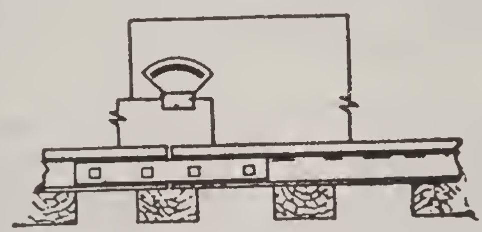


Figure 175

the voltmeter in the diagram are permanently fastened to bridge the bond, and the other wire is moved back and forth on the adjoining rail until a spot is found at which the voltmeter gives no indication while current is flowing. The resistance of the bond is now equal to the resistance of the length of rail between the other two wires. If any bond shows up much worse than the others, it should be attended to.

PHOTOMETRY

To measure the efficiency and the candlepower of different electric lights is a simple matter and much more attention should be given to such measurements than is usually accorded them by operators in charge

of illuminating stations. Thousands of dollars worth of fuel is wasted annually because owners and operators do not understand the loss of energy caused by continuing lamps of low efficiency in service.

There are two very simple methods of measuring candlepower; one of these is known as Rumford's, and is illustrated in Figure 176. A suitable pencil is set up about 2 inches from a wall of light color or a similar screen. A standard lamp is set up a convenient distance from this pencil, so as to cause a shadow from it to fall upon the screen. The lamp to be tested is

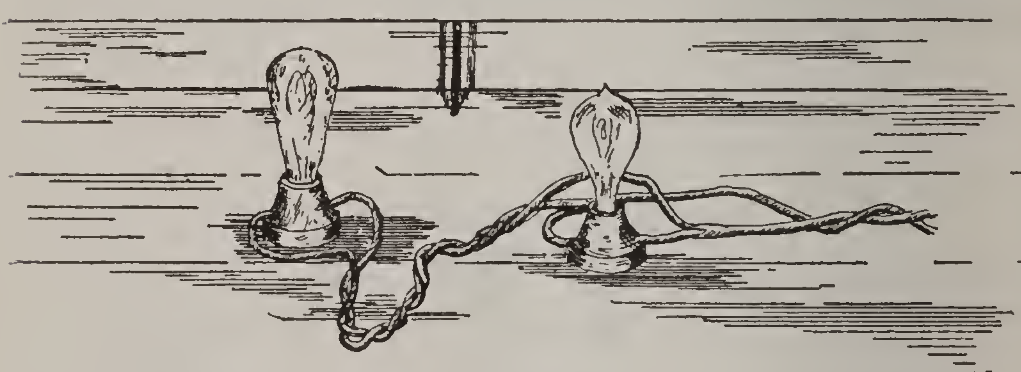


Figure 176

then set up in such a manner as also to cause the pencil to cast a shadow upon the same screen but at a different angle from the other. It will be noted that each lamp illuminates the shadow made by the other and that when the intensity of the two lights at the screen is equal, the shadows will be of equal darkness. The lamps must be adjusted at such distances from the screen that both shadows are equal. The candlepower of the two lamps is now proportional to the squares of the distance that each is from the screen. If one is 32 inches from the screen while the other is 23, the candlepower of the farther lamp is to that of

the nearer as 1024 is to 529, or nearly twice as great. In order to make this test as sensitive as possible it is best to move one of the lamps backward and forward in such a way as to be sure that it is a little too far in one positon and then a little too close in the other and then place it finally in an intermediate positon.

To measure the power consumed by each of the lamps an ammeter and a voltmeter are necessary. If connected as in Figure 176 the voltage of both lamps will be the same. The current consumed by each lamp can be gotten by removing one lamp at a time from the circuit, thus requiring only one ammeter. The efficiency of the lamp is usually expressed in watts per

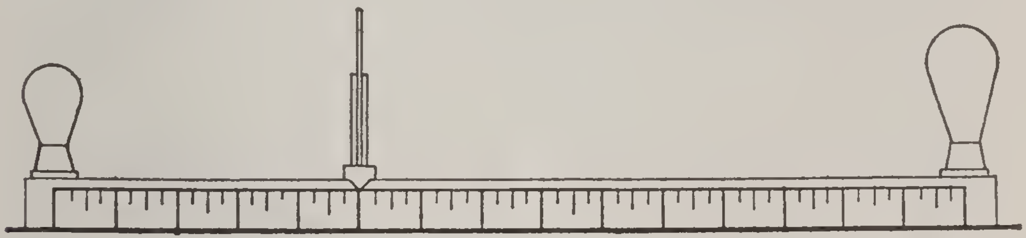


Figure 177

candlepower. If a certain lamp yielding 20 candlepower is taking 58 watts, there will be 2.9 watts per candlepower.

If lamps are to be tested for use on a certain circuit, the voltage of that circuit must be applied to them. The efficiency and candlepower of incandescent lights varies greatly with different voltages.

Another method, known as Bunsen's, is shown in Figure 177. A piece of blotting paper is soaked at a convenient place with oil or grease, so as to form a small spot. The paper is then placed between two lights and moved to such a position that the grease spot does not show. When this position is found, the

illumination on both sides is equal and the candlepower of the two lamps are as the square of their distance from the paper.

The illumination obtainable from a lamp varies greatly with the angle at which the light is taken, and also varies with the shape of the filament. It is further often purposely modified by the use of reflectors. In the illumination of desks, halls, etc., it is often important to know how a certain lamp or reflector distributes the light. For this purpose photometric measurements must be made at different positions under

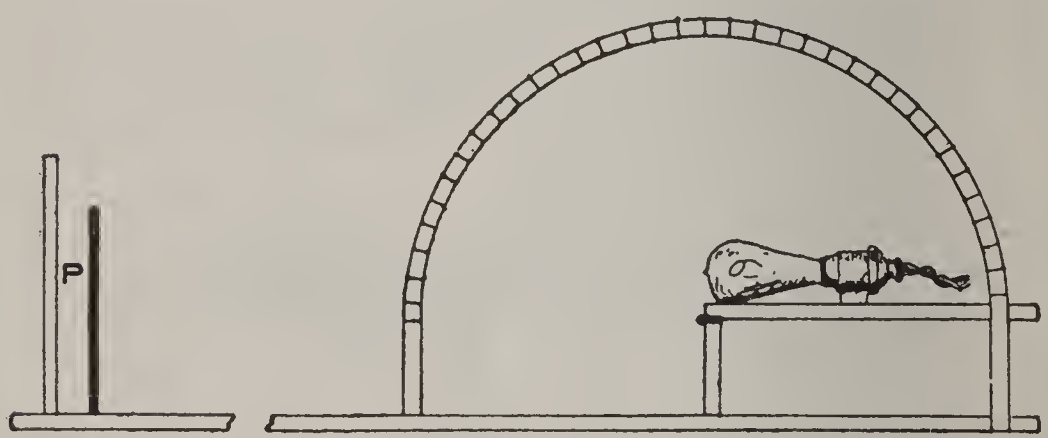


Figure 178

the lamp. This can easiest be done by an arrangement outlined in Figure 178. The lamp is fastened to a strip of wood hinged at one end so that it can be placed in different positions from horizontal to vertical through a range of nearly 180 degrees. In the position shown the light which strikes the pencil or grease spot P comes from the tip of the lamp, and is the same as would be found directly under the lamp if it were hanging. If the lamp is gradually raised and the candlepower taken at the different positions we can obtain a curve of the illumination throughout

one whole side of the lamp. At each change of position the candlepower must be measured and marked off on the radial line in Figure 179 that corresponds with the position of the lamp. When all of these have been marked, a curve may be drawn combining them which will represent the variation in candlepower. Such a curve representing half of the illumination from one lamp is shown in Figure 179. For this test

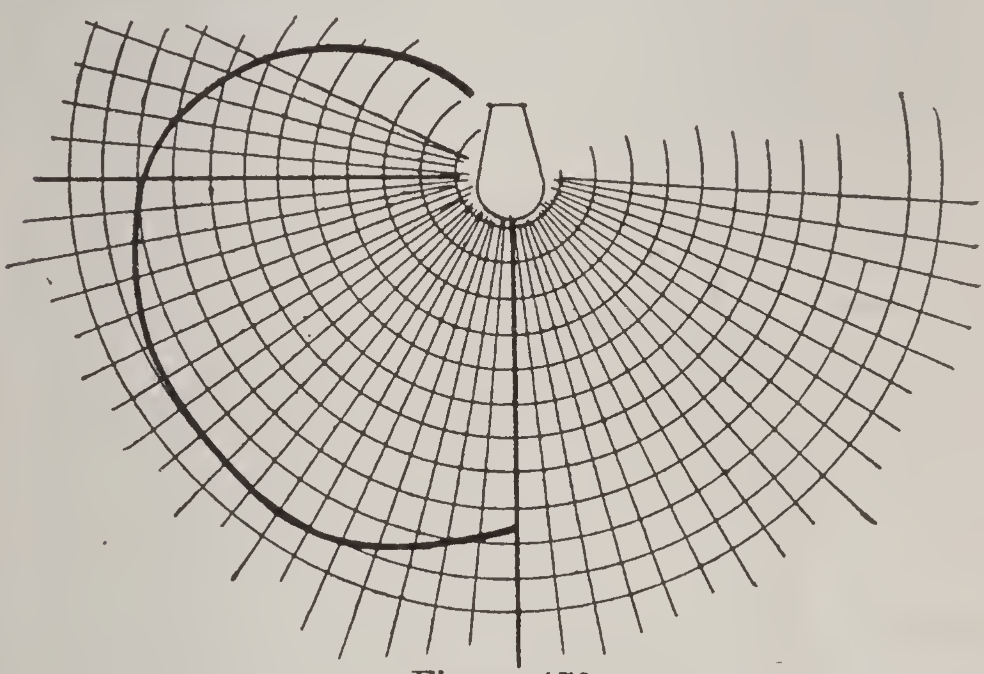


Figure 179

the board upon which the lamp lies should be painted black, so there may be no reflection.

When comparative tests are made care should be taken that the filaments of the lamps tested are about alike. An accurate comparison of different lamps requires the taking of complete curves as in Figure 145. These will give the average candlepower if properly figured up (add all of the measurements and divide by their sum) and also indicate whether the lamp is suited for the place where it is to be used.

The candlepower of arc lamps is often measured by means of the dispersion photometer first suggested by Prof. Ayrton. The principle of the arrangement is shown in Figure 180. The light from the arc is allowed to pass through a dispersion lens which spreads it out over a greater area and thus lessens its intensity.

Since the intensity of light varies as the square of the distance it follows that, using a dispersed light, we may consider the distance of the lamp from the screen as proportional to the square root of the area

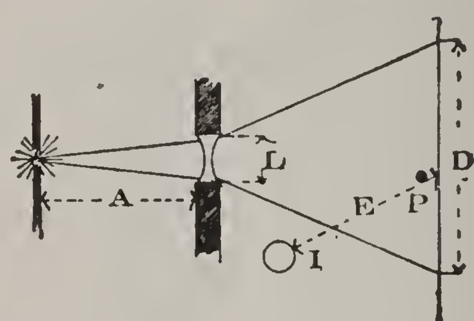


Figure 180

illuminated by the dispersed light. The lens limits the quantity of light, and as it is circular we may take the diameter of the circle illuminated as the square root of the area. The intensity of the light is then the same as though the distance from the arc to the screen were equal to D divided by L and multiplied by A; D being the diameter of the circle of dispersed light, L the diameter of the lens and A the distance from the arc to the lens. When the shadows cast by the arc and the standard lamp at the pencil P are equal, the candlepower of the arc is as much

greater as that of the standard I as $\left(A \times \frac{D}{L}\right)^2$ is greater than E^2.

Numerical example: Let A equal 24 inches, L equal 2 inches, D 18 and E 12; we have then 24×18 divided by 2 equals 216; this squared equals 46656, and this divided by 12^2 or 144 equals 324, which is the relative candlepower of the arc over the standard.

CHAPTER XX

DYNAMO AND MOTOR TROUBLES

DYNAMO TROUBLES

In this chapter the usual troubles occurring in dynamos are enumerated in the order in which it is most likely they occur. As a rule, time will be saved by testing for causes in the order in which they are listed.

FALURE TO GENERATE

Cause 1. Poor contact of brushes. This in turn may be due to dirty commutator, ragged brushes, insufficient tension on brushes, improper position of brushes. A rough commutator, if the dynamo is operating at high speed, may prevent contact even though at rest the connection may appear to be perfect.

Cause 2. Open circuit in the fields. In arc dynamos, this open circuit may be out in the line somewhere. Poor contact of brushes in series machines is equivalent to an open circuit.

Cause 3. Lack of residual magnetism. Test pole pieces with pliers or small piece of iron or steel; if there is no attraction, magnetize fields from a battery or from switchboard, if accessible. If magnetizing with one polarity does not start generation, try magnetizing in opposite direction. Sometimes generation

can be started by striking the pole pieces lightly with a hammer. Series dynamos can sometimes be started by short circuiting the brushes for a fraction of a second by fastening a wire to one of the brushes or terminals and wiping the other end across the other brush for the shortest possible length of time.

Cause 4. With shunt dynamos a short circuit connected to the dynamo will prevent generation entirely. With compound dynamos it may do so only to a certain extent. There will be some magnetism due to the series fields, but none due to the shunt. Disconnect everything from the dynamo except voltmeter.

Cause 5. Wrong connection of half of the fields; one opposing the other. This can be tested for with a compass. If the fields are right, each will attract a different end of the needle. Do not bring needle too close to either pole piece, or it may be reversed in polarity. By short circuiting first one and then the other it can also be determined whether both field coils are acting in the same direction. The needle must be attracted the same way, no matter which coil is cut out.

SPARKING OF BRUSHES

Cause 1. Wrong position of brushes. The brushes should be at the neutral point, and this can be found by moving back and forth until the point of least sparking is found. With increase of load the brushes must be shifted in the direction of rotation of the armature. When load decreases, the shifting must be in the opposite direction. The more modern dynamos require very little shifting with changes in load. In

connection with series arc dynamos the sparking at the brushes is unavoidable and special appliances are usually provided to take care of it.

Cause 2. Rough commutator, ragged brushes, or dirt on commutator.

Cause 3. Insufficient tension allowing the brush to leave the commutator.

Cause 4. Brush either too narrow or too wide. If too narrow it may leave one commutator section before making proper connection with the next. If too wide, it will short circuit several of the coils and the breaking of this current will manifest itself by sparking.

Cause 5. Brushes not correctly spaced. In two pole machines they should be diametrically opposite each other. Except in some special machines they should always be equally spaced.

Cause 6. Changes in load with some dynamos.

Cause 7. In compound d. c. machines wrong connection of series coils will cause sparking. In compound alternators a wrong setting of the commutator will cause sparking. If the load is inductive and changing, there must be a constant shifting with changes in load to prevent sparking.

Cause 8. Open circuit in armature. If this is the cause of sparking the sparks occur only at one place on the commutator and an inspection should reveal the location of the break. For exhaustive treatise on armature testing and repairing, see "Practical Armature and Magnet Wiring."

HEATING OF ARMATURE

Cause 1. Overload. Compare capacity of machine with load. The heating increases as the square of the current.

If several machines are operating in parallel, one may be running the other as a motor. With compound machines the ammeter may be cut into the same side as the equalizer and the reading may be altogether unreliable.

Cause 2. Short circuit in armature coil. This will speedily show itself by burning out. A strong odor of overheated shellac will be the first indication of trouble.

Cause 3. Defective construction; wires too small; foucault currents; hysterisis.

Cause 4. Poor ventilation. Some types are arranged so they can be either enclosed or opened at the ends.

INABILITY TO REGULATE VOLTAGE

Cause 1. Speed too low so that even with all resistance cut out of the regulator the resistance of the field circuit is too high to allow sufficient current to flow. Fields must be either rewound or connected in parallel, and a new suitable rheostat provided.

Cause 2. Speed too high so that even with all resistance in circuit the voltage is above that desired. To remedy this additional resistance must be provided unless, of course, the speed can be made correct.

FIELDS RUNNING HOT

Cause 1. Voltage at which machine operates much higher than intended.

Cause 2. Fields connected in parallel where they were intended to be in series.

Cause 3. Part of field cut out either by "ground" or improper connection of wires in coil. If this is the cause, one of the fields will be abnormally hot and the other cool.

SHOCKS OBTAINED FROM TOUCHING MACHINE

This is always due to either static electricity or grounding of some live part of the system on the frame of the machine. Static electricity is caused by the belting and can be remedied by providing arrester, or the shafting may be grounded.

To locate ground separate armature and fields and test for location. After this, the exact location can be found only by inspection and may require unwinding of coils.

SHAFT AND BEARINGS RUNNING HOT

Improper oiling. Box too tight. Rough bearing surface. Bent shaft. Excessive belt tension. End thrust due to improper leveling or armature not being centered and in consequence possessing a tendency to be 'sucked in," thus pressing heavily on one of the collars.

MOTOR TROUBLES

Fuses blow at starting.

Cause 1. Fuse may be too small, or contacts may be dirty or loose.

Cause 2. Motor may be overloaded, or stuck fast in some way.

Cause 3. Rheostat may be manipulated too fast. As a rule from 20 to 30 seconds should be consumed in the starting of the average motors.

Cause 4. Wrong position of brushes. Brushes should be at diametrically opposite points.

Cause 5. The voltage supply may be higher than the motor is designed for. If alternating the frequency of the supply may be lower than the motor requires. If the frequency is higher, not enough current can be obtained.

Cause 6. There may be a short circuit in the armature or in the field. A short circuit may be caused by two grounds in a two-wire sytem, or by one ground in three-wire system with grounded neutral.

Cause 7. The motor may be improperly connected.

Cause 8. The field circuit may be open, thus preventing the armature from generating the necessary counter E.M.F.

Cause 9. Light fields, due perhaps to grounded wires or short circuit of part of the coils. This will be indicated by part of the field running hotter than the rest.

FAILURE TO START

Fuses do not blow.

Cause 1. Dead line. Test for current at switch.

Cause 2. Open circuit in armature or fields, if series motor. In armature only if shunt or compound motor.

Cause 3. Poor contact of brushes or insufficient tension.

If alternating, frequency of supply may be too high. Synchronous motors must be started independently of the current.

SPARKING OF BRUSHES

See "Dynamo Troubles."

Sparking of motor commutator is often much more troublesome than with dynamos, because the load changes are more frequent and sudden. Since compound motors are wound with series fields opposing or helping the shunt fields, frequently the sparking may be due to wrong connection of the fields

RACING OF MOTOR

Cause 1. Series motors require constant regulation if connected to variable load. If the load is light, motor will speed up.

Cause 2. Light fields due to improper winding, grounds, short circuit or improper connection will cause any motor to speed up unless heavily loaded. Fields intended to be in parallel may be in series. Part of the field winding may be connected to oppose the rest. The compound coils may be in opposition to the shunt coils. In such a case the speed of motor will increase with increase in load until if overloaded the fields will become so light that finally fuses will blow. Strength of field cannot be altered by adding or removing wire. It must be rewound with larger wire, if field is too light, and with smaller if field is too strong.

MOTOR NOT UP TO SPEED

Cause 1. If series motor, it may be overloaded.

Cause 2. The line supplying current may be so long and the wire so small that with a heavy load the speed of motor falls off considerably. This condition would not affect a motor running light.

Cause 3. Fields may be too strong. Fields intended to be run in series may be in parallel. In such a case they will likely run hot.

FIELDS OR ARMATURE RUNNING HOT

See "Dynamo Troubles."

MOTOR RUNNING IN WRONG DIRECTION

Remedy by reversing connections of fields or armature. If both are reversed, it will have no effect. As long as fields and armature polarity remain in the same relation to each other, the polarity of the supply line is immaterial.

Multipolar motors and also some bi-polars can be reversed by shifting the brushes so that the negative brush takes place of the positive. Three-phase motors are reversed by changing any two of the wires. Two-phase motors are reversed by reversing the wires of one of the phases.

HEATING OF MOTOR

Cause 1. Overload.

Cause 2. Voltage too high.

See, also, "Heating," under Dynamo Troubles.

With induction motors one of the phases may be

out. A three-phase motor will continue to run on one phase, but will not start. If such a motor is overloaded, it will come to rest and burn out.

The above includes all of the common troubles encountered on ordinary motor circuits. Motors are, however, used in so many complicated systems of wiring, as, for instance, in connection with printing presses where multi voltage control is often used and where motors must be reversible and capable of being started or stopped from different places, that the only way for an operator to fit himself to deal with troubles on such systems is to thoroughly acquaint himself with the details of the wiring. He should draw out an accurate diagram of the connections showing the location of every wire and learn exactly what its purpose is and study this diagram patiently, trying out what effect a short circuit at one place or a broken or a misplaced wire at another would have.

By preparing himself in this manner a repairman can do in a few minutes what might otherwise require hours for, and where the loss due to an idle machine is figured at from ten dollars per hour upward, speed in locating trouble is of the utmost value.

CHAPTER XXI

RECORDING WATTMETERS

To obtain a record of the amount of electrical energy consumed on a circuit in a given time, it is necessary that some suitable form of instrument be so connected in the circuit that a continuous record of the amount of energy passing over the circuit is recorded. The chemical meter, a diagram of which is shown in Figure 182, was originally used for this purpose. This meter consists of zinc plates suspended in a conducting solution, so arranged that a part of the total current used on the circuit passes between these plates. At certain intervals the plates were removed and weighed, the amount of metal deposited on one of the plates showing the amount of current used during the interval.

This meter was in reality a current meter, as it did not take into account the variations in voltage on the line except, of course, as these might affect the current. To reduce the reading to watts it was necessary to estimate the average voltage during the period which the meter was in use. Considerable work was entailed in the "reading" of these meters, as it was necessary for the meter man to carry with him enough plates to replace those removed and to carry back to

the laboratory for weighing all the plates removed. This type of meter had other disadvantages among which was the inability of the consumer to check the readings, and the fact that the meter could not be used on alternating currents; and they are now entirely replaced by the mechanical meters.

It was customary when the chemical meter was in use, to show in the monthly statements sent to con-

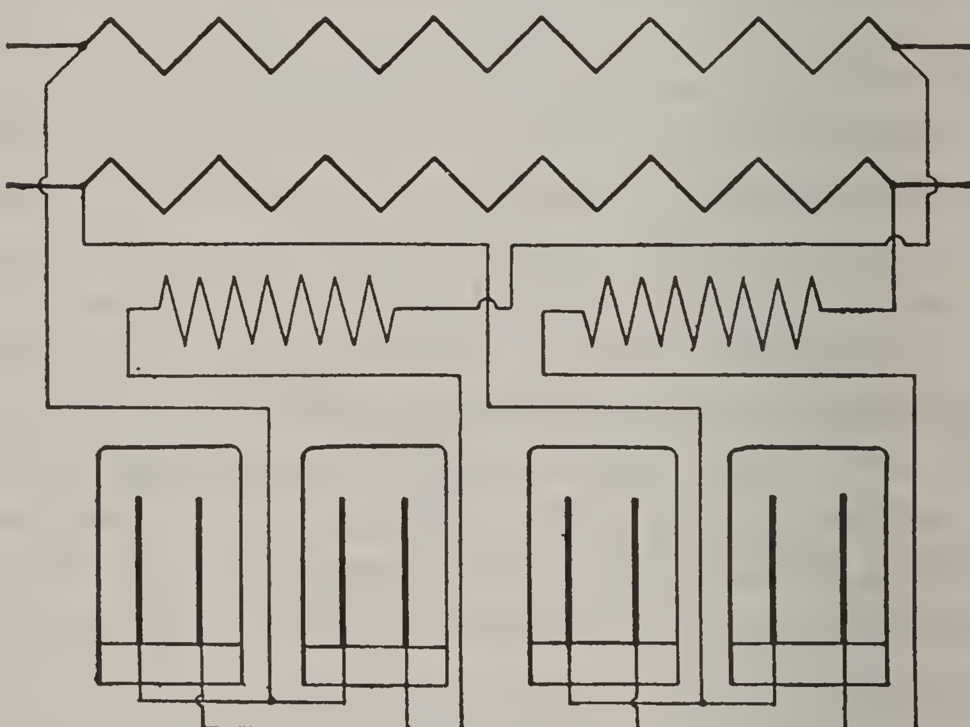


Figure 182

sumers the number of lamp hours or the number of ampere hours used during the period. The first mechanical meters were simply recording ammeters and registered the amount of ampere hours or lamp hours. At the present time the wattmeter is used almost exclusively.

The "watt" is the unit of electrical power and is the basis of all wattmeter readings. A kilowatt or

K. W. is 1,000 watts. An electrical horsepower is equivalent to 746 watts. For approximate calculations, a horsepower is considered as equivalent to 750 watts or ¾ of a kilowatt; likewise a kilowatt is equal to 4/3 of a horsepower. A current of one ampere flowing through a resistance of one ohm will produce one watt, the E.M.F. being in this case, according to Ohm's law, one volt.

Expressed in symbols $W = IE$, $W = I^2R$, $W = \dfrac{E^2}{R}$.

An incandescent lamp taking ½ ampere at 110 volts, takes $\frac{1}{2} \times 110 = 55$ watts. The same lamp, when burning, has a resistance of 220 ohms. The wattage is, therefore, according to the formula, $W = I^2R$, $(\frac{1}{2})^2 \times 220 = 55$ watts.

While the "watt" expresses the rate at which power in an electrical circuit is used, it does not express the amount of work performed. To correctly indicate the actual work done, the length of time during which the power is acting must be taken into consideration. The unit of electrical work is the "watt hour," meaning that one watt is used for one hour.

The distinction between a watt and a watt hour is similar to the distinction between the speed at which a train moves and the distance which it covers. To find the distance covered by the train we must multiply the speed (miles per hour) by the number of or fraction of an hour that the train moves at this speed. In the same way to get the actual power consumed in

a circuit, we must multiply the watts consumed by the length of time.

An incandescent lamp taking 55 watts will, in one hour, require 55 watt-hours of energy. Ten such lamps operated for one hour would require 550 watt-hours; or one such lamp operating for 10 hours would require 550 watt-hours. In a like manner, a horse-

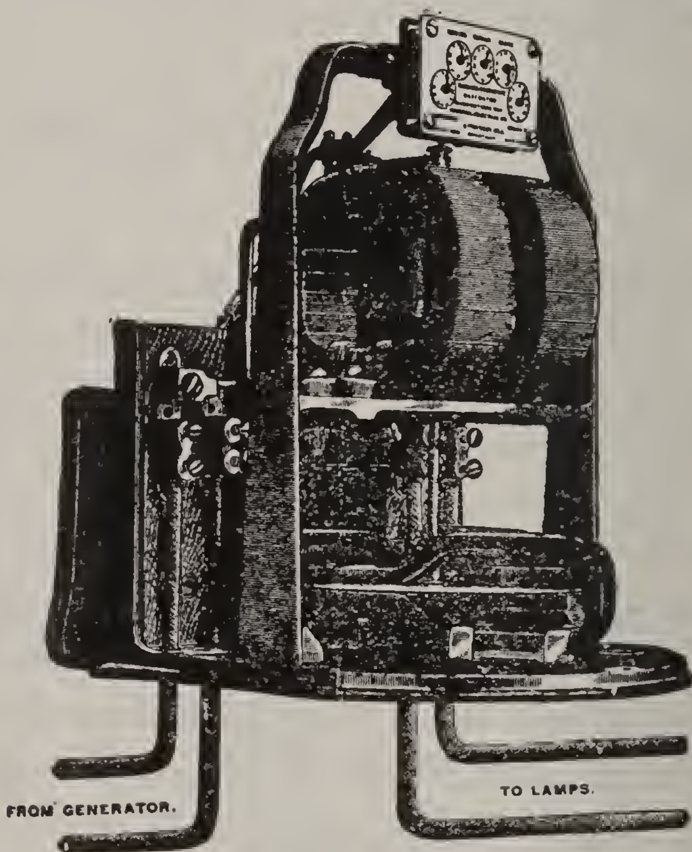


Figure 183

power (746 watts) in use for one hour will require 746 watt-hours. The watt-hour is too small a unit for commercial purposes and the kilowatt hour, or 1,000 watt-hours, is generally used.

While it will be seen that there is a decided difference between the terms "watt" and "watt-hour," still it will be found that the two are frequently used synonymously, kilowatt-hours often being referred to

as kilowatts. The connection in which the term is used will determine the meaning. For instance, a monthly statement referring to so many kilowatts must, obviously, mean kilowatt-hours.

The recording wattmeter, sometimes called integrating wattmeter, owing to the fact that it indicates the total watts used, consists of a small motor operated by the current to be measured. Figure 183 shows a view of the Thompson recording wattmeter and Figure 184 a diagram of the connections. The upright shaft

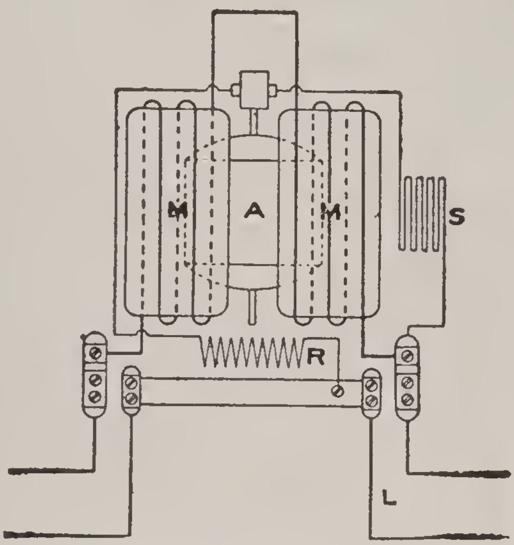


Figure 184

in the center of the meter supports the armature A, Figure 184. To reduce the friction to the smallest possible amount this shaft rests on jewel bearings.

The coils of armature A are composed of fine wire which terminates in a silver commutator. Brushes, lightly bearing on this commutator, convey the necessary current to the armature. The armature, which is connected in series with a non-inductive resistance R, and the auxiliary shunt field S, is connected directly across the mains. The two field coils M M are wound

with a rather heavy wire and connected directly in series with one of the mains. At the lower end of the shaft is a copper disk, shown in Figure 183, which rotates freely between the permanent magnets. A clockwork geared to the upper end of the shaft records the revolutions of the armature. The scheme of connection is plainly shown in Figure 184.

The armature and the shunt field S are always in circuit, but as their resistance is very high the current is small. The tendency to turn, due to the current in the armature, is only affected by the voltage across the mains. If the two field coils were replaced by permanent magnets we would have in reality an instrument which would, with a suitable arrangement of springs and a pointer, serve as a voltmeter and would only be affected by changes in voltage across the mains. The two coils M M, which are connected in series with one of the mains, form the field in which the armature rotates. The greater the strength of this field, the greater the speed of the armature. It will therefore be seen that the effort which revolves the armature is the result of the current in the coils M M and the E.M.F. in the armature, the combination of these two being I $\times$ E or watts.

In order that the speed of the armature may be in exact proportion to the watts used, a copper or aluminum disk attached to the armature shaft is arranged to rotate, without touching, between a pair of permanent magnets. A current is generated in this disk, in a manner similar to that in which current is generated in the armature of a dynamo, and tends to retard the disk. The effect of this retardation is such that the

rate at which the armature revolves is in exact proportion to the wattage used on the circuit.

Although every effort is made to reduce the friction to the smallest extent possible, by providing jewel bearings and by making the armature, shaft and disk of very little weight, still it is impossible to entirely do away with it. Some energy, although a very small amount, is also required to operate the clockwork of the registering mechanism. The shunt field S, connected in series with the armature circuit, is so arranged that it tends to start the armature and overcome the friction of the revolving element. The meter will, therefore, register on light loads and register more accurately at all other loads. As the torque exerted by the shunt field is the result of the current in it and that in the armature, it is evident that a change in the voltage across the mains will also affect the starting torque, the variation being proportional to the square of the E.M.F. The shunt field should therefore be adjusted for the voltage of the circuit on which it is to be used.

It will be noted that the connection for the shunt field is made on the load side L of the meter. With this connection the meter will register the amount of current used in the armature circuit. On the other hand, if the connection for the shunt field circuit was made on the generator side of the meter it would receive a slightly higher pressure and take into account the loss in the main coils M M. The loss in either case is very small.

Meters of the Thompson type may be used with either direct or alternating current circuits as there

is no iron used in their construction and the inductance is therefore small. Where used on alternating current circuits the reversals of the current in both the armature and fields occur at the same time and the meter will continue to revolve in the one direction, for, it is well known, changing the direction of current in a shunt motor does not change the direction of rotation of the armature. If, however, the meter is fed from the wrong side it will run backward. This can readily be understood by referring to Figure 184. As long as the polarity of the supply circuit is not reversed the armature current remains in the same direction but the direction of the current through the fields depends upon from which side the meter is fed.

For the measurement of power on alternating current circuits meters of the induction type possess a number of advantages and are used almost exclusively. These meters are used on alternating current circuits only, the rotation of the revolving element being obtained by the joint action of a set of series coils and a shunt coil inducing current in a metal disk. The reaction of this induced current causes the armature to revolve in much the same way as that of an ordinary induction motor. As the same disk is acted upon by both the coils which produce the rotation and the permanent magnet which retards the rotation the weight and consequently the friction may be kept down to a minimum. The use of a commutator and its brushes are unnecessary as there is no winding on the revolving element.

Figure 185 shows a view of the Guttman wattmeter with the dials and magnets removed. The aluminum

armature which is slotted in spiral lines weighs about 3/4 of an ounce and rests on a jewel bearing. At the top of the spindle is a worm whereby the motion of the revolving element is transmitted to the recording train. The two series coils, shown directly at the left of the spindle, are mounted on aluminum frames. The

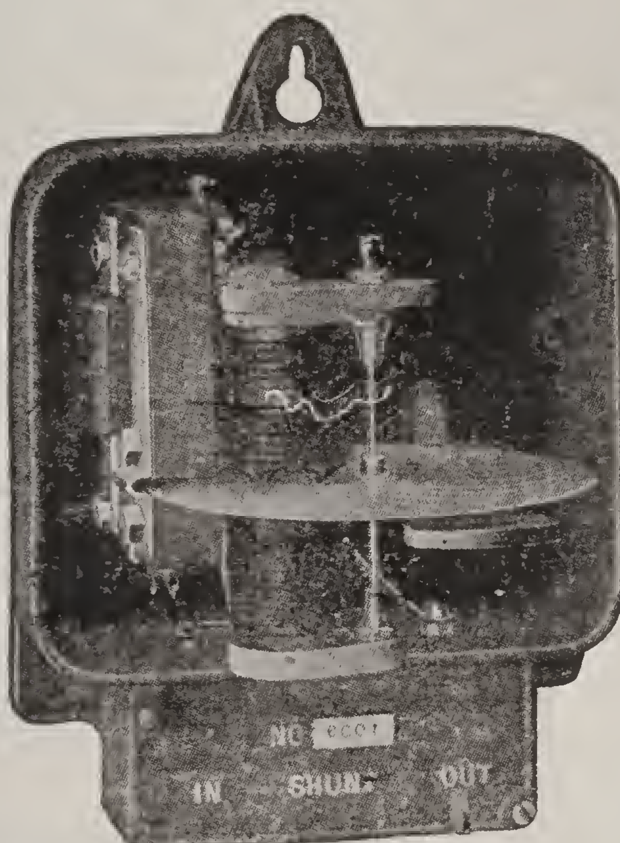


Figure 185

coils are wound with heavy wire and consume from two to four watts, depending on the size of the meter.

The shunt coil of the meter is wound upon a laminated iron core having two air gaps, through one of which the disk rotates. On the lower part of this laminated core a heavy band of copper partially surrounds the iron laminations. An adjustable piece of

wire is connected to the two ends of the copper band and completes an electrical circuit.

In order that the meter may register accurately on inductive loads it is necessary that the current in the shunt field lag behind that of the series field by an angle of 90°. This will be clearly understood by considering the conditions which would exist were the two currents in exact phase. If such was the case the instrument would become a recording volt-ampere meter and would take into account only the amperes as they would be indicated by an ammeter. On an inductive load the product of the volts and amperes does not represent the wattage and to obtain the true value of the watts the power factor must be considered.

The greatest torque or turning moment must be exerted on the revolving element of the meter when the load is non-inductive, for then the power factor is 1 and the product of the volts and amperes represents the true power. On the other hand the least torque should be in effect when the load is all inductive or when the power factor is 0, for then there is no true energy represented.

In order that the current in the shunt coil may lag 90° behind the impressed E.M.F. this coil is wound on the iron core to give this circuit the greatest possible inductance, but as this inductance alone cannot produce a difference of phase of 90° other means must be resorted to. This is accomplished by means of the copper band referred to above, which, forming a closed circuit around this iron core, has a current induced in it, and this current reacting upon the field produced by the shunt coil gives the effect desired.

INSTALLATION OF METERS

The manner in which a meter is connected into the circuit depends upon the wiring system, and the current and voltage used. Although the structural features of the various makes of meters differ the general scheme of connecting them into the circuit is similar.

Figure 184 shows the Thompson meter as used on a two-wire circuit. Both mains are carried to the meter, one of them being connected to the series coil and the

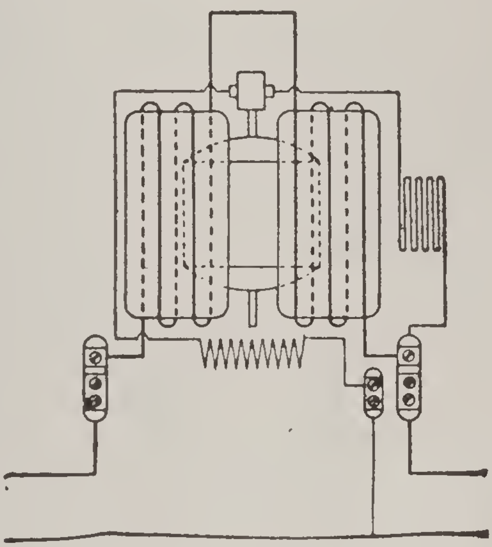


Figure 186

other passing through the meter by the bus bar connection. The shunt armature circuit is, however, connected to this bar.

With large mains only one wire is carried through the meter, this being connected to the series coils. A tap taken off the other main connects to the shunt coil as shown in Figure 186. As this shunt tap carries only current for the shunt field of the meter it may be of small wire, generally No. 14 B. & S. gauge.

When a meter is connected in a three-wire circuit

both outside mains are carried through the meter, one through each of the series coils. The shunt field is connected by means of a wire tap to the neutral main. The Thompson three-wire meter is shown in Figure 187. In some types of three-wire meters no neutral tap is used, the shunt circuit being connected directly across the outside mains. This connection has an advantage in that it does away with the running of one wire to the meter and, as the shunt field connection is

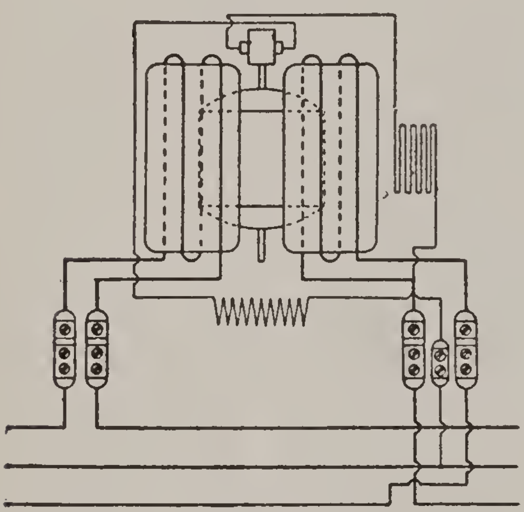


Figure 187

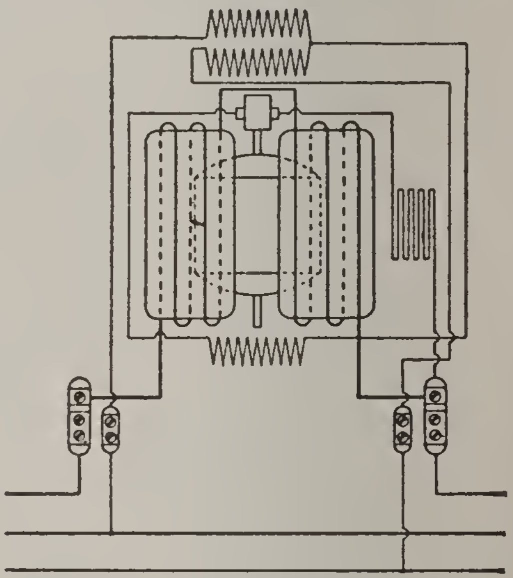


Figure 188

inaccessible the possibility of tampering with the meter is reduced. It has, however, the disadvantage in that an added resistance must be placed in series with the shunt field when used on direct current circuits with the consequent increase in the power consumed by the meter.

Figure 188 shows the connections for a meter on a balanced three phase circuit. One main is carried through the series coil of the meter and two taps from the other two main wires are carried to a common con-

nection through an inductive resistance and connect to the shunt field circuit.

On alternating current circuits of large capacity it is not advisable, for several reasons, to carry the

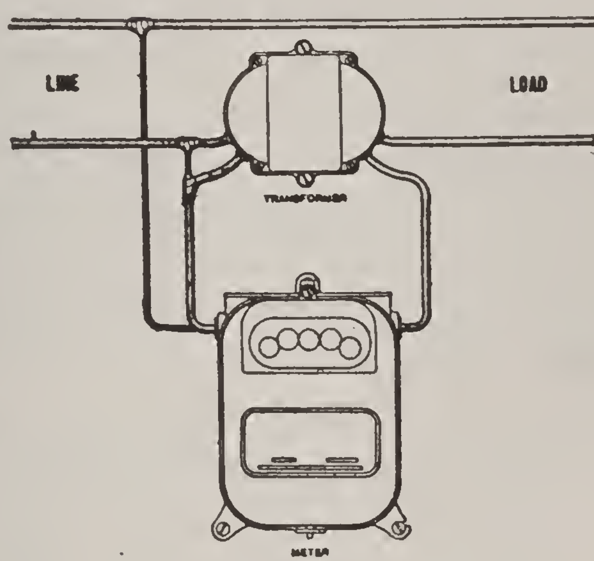


Figure 189

mains through the meter. A small current transformer is connected in series with one of the mains, the secondary of the transformer being connected to

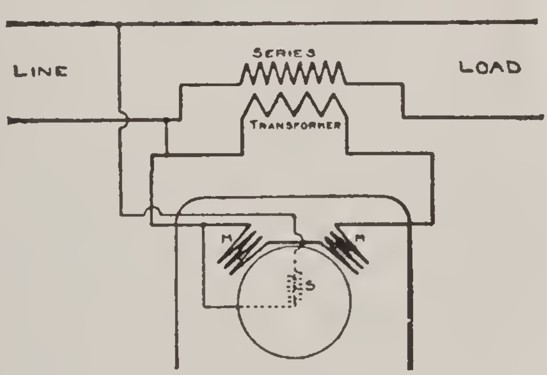


Figure 190

the meter as shown in Figures 189 and 190. If the meter is used on a primary circuit or on any circuit where the voltage is high a small potential transformer may be connected across the mains and the shunt field con

nected directly to the secondary as shown in Figures 191 and 192. Various other combinations of both current and potential transformers are made use of; as, for instance, on a three-wire circuit of large capacity. In this case two current transformers are used, one on each main, the secondaries being connected to the series coils of the meter.

Detailed instructions are generally sent out for the installation of individual meters but there are a few

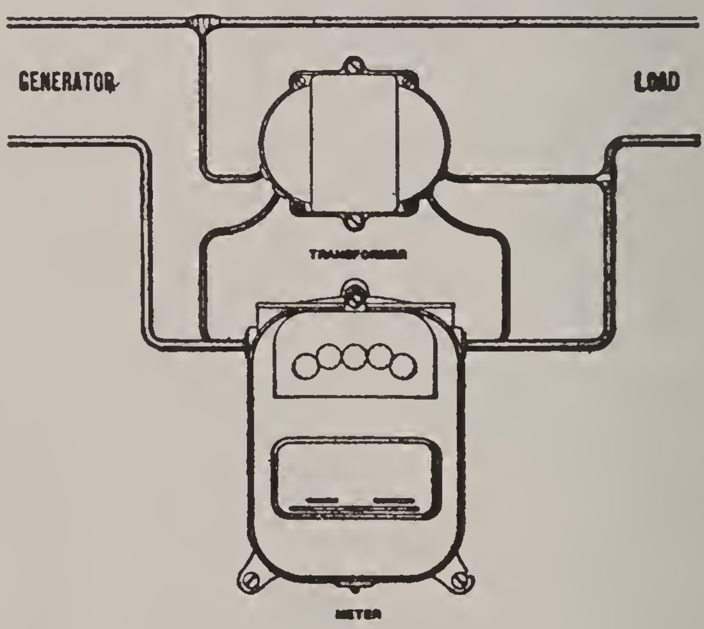


Figure 191

general directions which apply to all. A meter is a somewhat delicate instrument and, although built to withstand ordinary usage, efficient operation demands careful and intelligent handling. As has been stated, the revolving element of recording wattmeters rests on jewel bearings. A slight jar is often all that is necessary to injure or break the jewel. For this reason some means is always provided to remove the revolving element from contact with the jewel when the

meter is to be carried about or during transportation, and the moving element should never be placed in contact with the jewel until the meter is ready to be started.

When a meter is unpacked it should be carefully cleaned and examined. Some care should be exercised in the choice of location for setting the meter. To obtain the most efficient operation it should not be placed where it will be subject to any vibration, neither should it be placed in an extremely hot or cold place or where subject to great extremes of temperature.

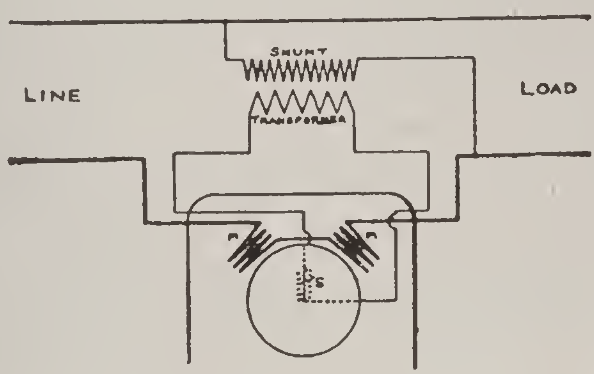


Figure 192

Locations where dust, moisture, or inflammable or corrosive vapors are present should also be avoided.

The meter should be installed in a readily accessible location and should be fastened to a solid upright support. A hole for a supporting screw is generally provided at the top of the meter and a screw (never use a nail) should be inserted at this point first. The meter should then be leveled. A small spirit level may be used for this purpose or, where the meter has a disk, a small weight of some non-magnetic substance such as brass may be placed near the outer

edge of the disk. If the meter is not level the weight and disk will revolve to the lowest point.

Place the weight on the front or back upper surface of the disk. If the disk rotates to the right or left that part of the meter toward which it rotates is low and the bottom of the meter should be moved in that direction. When the meter is level from right to left the disk and weight will not move when the weight is placed at the center of the disk at the front or back.

Now place the weight on either side of the disk and note if the disk rotates to the front or back. If to the rear the back part of the meter is too low and the meter should be moved out at the top. If the disk rotates to the front that part of the meter is too low and should be moved out at the bottom. When a perfectly level position has been obtained the weight will not move if placed on any part of the disk It is well to check back after the last leveling as the first position may have been altered. All the screws should now be set up.

The wires may now be connected to the meter, being careful to follow the wiring scheme applying to the particular meter. The wires should be thoroughly cleaned and the binding posts tightly set up to avoid any heating at these points. Now place the revolving element on its jewel if this has not already been done and turn on the current and note if the meter revolves in the proper direction. The meter case may now be placed on the frame, paying special attention to see that the case closely fits into place and no opening is left at the edges.

TESTING

A recording wattmeter is so designed that with a given wattage passing through the meter a definite number of revolutions of the armature will result. For instance, on a certain type of meter it takes 18 seconds to complete one revolution of the armature on 100 watts, or 1800 seconds for one revolution on 1 watt. This is the equivalent of 1/1800 of one revolution for one seond on one watt. On this type of meter the armature would require 1800 seconds to make one revolution while only one watt is passing through the meter and this is taken as the testing constant of the meter. To determine the wattage at any load multiply the revolutions per second, or $\frac{\text{revolutions}}{\text{seconds}}$, by the constant. As an example: Suppose the meter made one revolution in one second, $\frac{1}{1} \times 1800 = 1800$ watts passing through the meter.

In order that the same type of meter may be used on circuits of different voltages it is customary to introduce a resistance in series with the shunt circuit; so that no matter what voltage may be used on the meter the armature circuit will always have impressed upon it the same voltage. The number of revolutions of the armature will then be the same even though the voltage on the meter and correspondingly the wattage, has been increased. To make this meter indicate cor-

rectly the train gear is altered to indicate correct readings. For instance, with a certain meter designed for use on a 110 volt circuit it requires 2000 revolutions of the armature to register 1000 watts. If the same meter was used on a 220 volt circuit, with a resistance in series with the shunt circuit so that the shunt circuit would only receive 110 volts, the true wattage would be registered by arranging the gearing so that one revolution of the armature would produce twice the movement of the pointer on the dial. The testing constant would also be doubled.

As meters of large capacity require a larger wire for the winding of the series coils, and as it is not advisable to run the meter at too high a speed, the field due to the series winding is cut down and fewer revolutions of the armature will result with a given load. In this case the train ratio and the testing constant are increased.

Below are given the testing formulas for calibrating recording wattmeters.

FORT WAYNE

$$\frac{\text{Rev.} \times 100 \times \text{Constant}}{\text{Seconds}} = \text{Watts}$$

See Instruction Book for Constants.

WESTINGHOUSE

$$\frac{\text{Rev.} \times \text{Constant}}{\text{Seconds}} = \text{Watts}$$

Constant = 1.2 × (Amp. × Volts as marked on dial).

On types B and C, Constant = 2.4 × Amp. × Volts as marked on dial).

GENERAL ELECTRIC, DUNCAN AND SCHEEFER

$$\frac{\text{Rev.} \times 3600 \times \text{Constant}}{\text{Seconds}} = \text{Watts}$$

G. E. Non-Direct Reading, Constant on dial.

G. E. Direct Reading, Constant found on disk.

Duncan, Constant on dial. (Fort Wayne Induction type.)

Duncan, Constant on disk (Direct current and S. & H. Induction type).

Scheefer Non-Direct Reading, Constant on dial.

STANLEY

$$\frac{\text{Rev.} \times 100 \times \text{Constant}}{\text{Seconds}} = \text{Watts}$$

Constant = Seconds required for meter to make revolution on 100 watts.

Constant stamped on case.

GUTTMAN

$$\frac{\text{Rev.} \times \text{Constant}}{\text{Seconds}} = \text{Watts}$$

$$\text{Constant} = \frac{3600}{\text{Train ratio as found on meter}}$$

SANGAMO

$$\frac{\text{Rev.} \times \text{Constant}}{\text{Seconds}} = \text{Watts}$$

Constant found on back of meter.

Any of these formulas may be rearranged for convenience in testing.

$$(1) \quad \text{Watts} = \frac{\text{Revolutions} \times \text{Constant}}{\text{Seconds}}$$

$$(2) \quad \text{Revolutions} = \frac{\text{Watts} \times \text{Seconds}}{\text{Constant}}$$

$$(3) \quad \text{Seconds} = \frac{\text{Revolutions} \times \text{Constant}}{\text{Watts}}$$

$$(4) \quad \text{Constant} = \frac{\text{Watts} \times \text{Seconds}}{\text{Revolutions}}$$

$$\text{Error} = \frac{\text{Observed secs.} - \text{Secs.}}{\text{Secs.}}$$

The testing of a wattmeter can be accomplished in several ways, the choice of method depending on the

accuracy desired and the apparatus at hand. One of the simplest methods is that of turning on a number of 16 candlepower lamps and then counting the number of revolutions of the meter disk in a given time. The load is estimated and the meter checked up by using the formula of the type of meter under test. As an example: Suppose ten 16 candlepower lamps, taking 50 watts each, are turned on. The time required for one revolution according to formula (3) would be

$$\text{Seconds} = \frac{1 \times 1800}{500} = 3.6 \text{ seconds.}$$

If the meter made

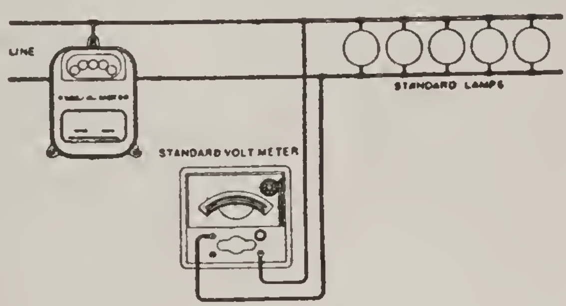


Diagram No 1

Figure 193

exactly ten revolutions in 36 seconds it would be registering correctly. At best this method is only approximate as the wattage of the lamps must be estimated and this will vary considerably with different makes of lamps and lamps of different ages.

To make this test more accurate a number of lamps may be prepared by ascertaining the watts consumed by each at several different voltages such as will be met with on the tests. These voltages and the corresponding wattages should be marked on labels on the lamps. When a meter test is made a reading should

be taken of the voltage with a portable voltmeter and the exact load can then be determined. See Figure 193.

A regular service meter accurately calibrated in the shop or laboratory may be used in checking up other meters by connecting it in circuit as shown in Figure 194. With the connection shown the voltage impressed on the shunt coils of the two meters is equalized and the inaccuracy which would result were the meters connected side by side, where the shunt coil of one meter would be subjected to the reduced voltage caused

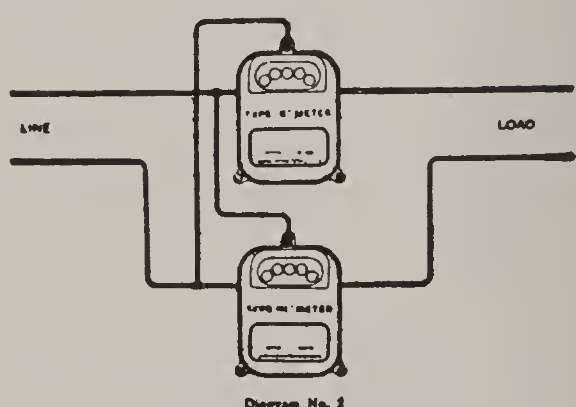


Figure 194

by the drop in the series field of the other meter, is avoided. If the two meters are of the same type and capacity the two revolving elements will rotate in unison when the meter being tested is correct. If the meters are of different capacity this must be taken into account.

The most accurate test and the one more generally used is shown in Figure 195. Figure 195 shows corrections for a standard wattmeter. The wattmeter is sometimes replaced by a voltmeter and ammeter. On direct current circuits either method may be used, but the wattmeter is more convenient and accurate. For

alternating currents the reading obtained by multiplying together the amperes and volts does not represent the true wattage of the circuit unless the load is non-inductive. For inductive loads a wattmeter must be used, but it is well to take both the wattmeter and the volt-ampere readings so that the power-factor may be known.

Figure 196 shows connections for testing a three wire meter using one standard wattmeter. The load must first be balanced and the neutral fuse then opened.

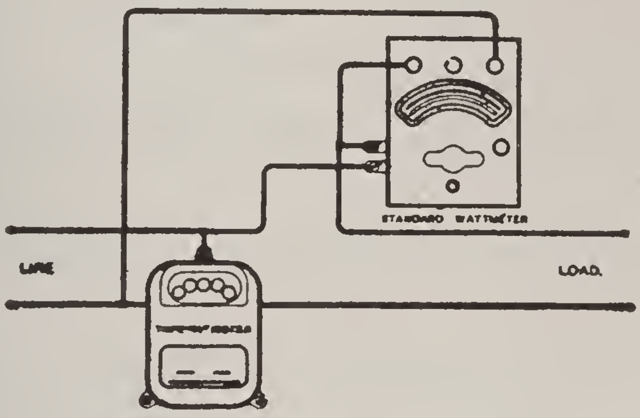


Figure 195

This method is objectionable where the shunt coil of the meter under test is connected directly across the mains as the shunt coil of the standard wattmeter is subject to the variation in voltage between the neutral and the outside wires. To overcome this objection a multiplier may be used in series with the shunt coil of the standard meter and connection can then be made directly across the outside mains. If the shunt circuit of the meter under test is connected between one of the outside mains and the neutral wire a test may be made by using one standard wattmeter and connecting

up only one series coil of the meter under test at a time, or both series coils may be connected in series.

The most accurate method of testing three-wire meters is by use of two standard wattmeters con-

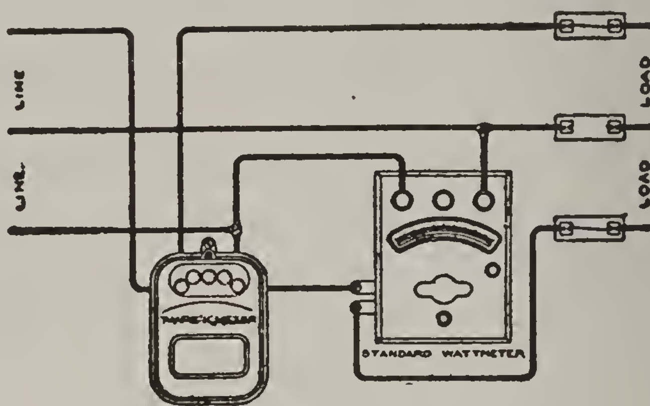


Figure 196

nected as shown in Figure 197. The sum of the standard meter readings should equal the reading of the meter being tested. In this case it is not necessary to balance the load.

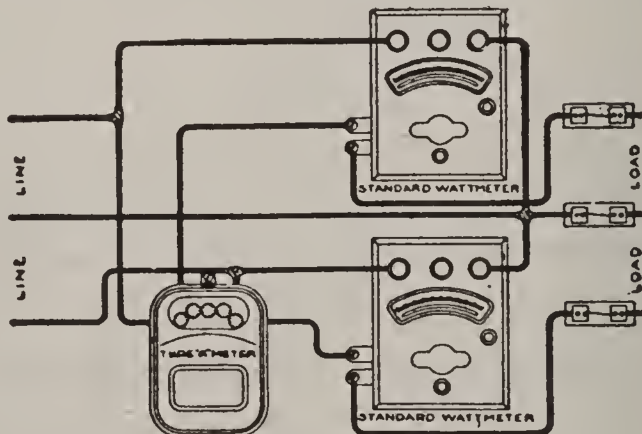


Figure 197

It is of great importance for accurate testing that a good stop watch be employed, although for approximate tests the second hand of the ordinary watch serves the purpose quite well. The longer the time of the test, using the latter method, the less the error.

When the apparatus is set up ready for the test, a small load, about 10 per cent of the full load capacity of the meter, is turned on. The number of revolutions made by the revolving element and the time over which the count is made are noted. By means of formula 1 the watts as indicated by the meter under test are compared with the wattage of the standard meter. The per cent of standard watts will be $\dfrac{\text{Meter watts} \times 100}{\text{Standard watts}}$. Example: Suppose the revolving element made 13 revolutions in 90 seconds, the testing constant of the meter being 1800. Watts $= \dfrac{13 \times 1800}{90} = 260$ watts. If the standard meter indicated 250 watts the percentage of standard watts would be $\dfrac{260 \times 100}{250} = 104$ per cent, or 4 per cent fast.

A method frequently used, and one by which the percentage error may be taken direct from a previously prepared table, is as follows: Ascertain the watts of the connected load from the reading of the standard wattmeter. From the following formula determine the number of revolutions the meter under test should make in one minute. $\dfrac{\text{Watts of load} \times 60}{\text{Testing constant of meter}} =$

Revolutions per minute. Now note the number of seconds required by the meter under test to complete this number of revolutions. If the number of revolutions are completed in exactly 60 seconds, the meter is correct; if not, the meter is fast or slow. Example: On a load of 150 watts it is found that exactly 5 revolutions are completed in one minute or 60 seconds. Testing constant of meter is 1800. According to formula 2

Revolutions $= \dfrac{150 \times 60}{1800} = 5$. If this meter had completed 5 revolutions in 55 seconds it would be $\dfrac{60 \times 100}{55}$ $= 109.09$ per cent, or 9.09 per cent fast. If five revolutions had been completed in 67.8 seconds, it would be $\dfrac{60 \times 100}{67.8} = 88.5$ per cent, or 11.5 per cent slow.

The following table gives the per cent of error for time in fifths of a second.

PER CENT ERROR TABLE FOR FIFTHS OF A SECOND.

Time in Seconds	Per Cent Fast	Time in Seconds	Per Cent Fast	Time in Seconds	Per Cent Slow	Time in Seconds	Per Cent Slow
40.20	49.25	50.20	19.52	60.20	0.33	70.20	14.52
.40	48.51	.40	19.05	.40	0.67	.40	14.77
.60	47.78	.60	18.58	.60	0.99	.60	15.01
.80	47.06	.80	18.11	.80	1.31	.80	15.25
41.00	46.34	51.00	17.65	61.00	1.63	71.00	15.50
.20	45.63	.20	17.19	.20	1.96	.20	15.73
.40	44.93	.40	16.73	.40	2.27	.40	15.96
.60	44.23	.60	16.28	.60	2.59	.60	16.20
.80	43.54	.80	15.83	.80	2.91	.80	16.43
42.00	42.86	52.00	15.38	62.00	3.22	72.00	16.66
.20	42.18	.20	14.94	.20	3.53	.20	16.89
.40	41.51	.40	14.50	.40	3.84	.40	17.12
.60	40.85	.60	14.07	.60	4.15	.60	17.35
.80	40.19	.80	13.64	.80	4.45	.80	17.58
43.00	39.53	53.00	13.21	63.00	4.76	73.00	17.81
.20	38.89	.20	12.78	.20	5.06	.20	18.03
.40	38.25	.40	12.36	.40	5.36	.40	18.25
.60	37.61	.60	11.94	.60	5.66	.60	18.47
.80	36.98	.80	11.52	.80	5.95	.80	18.70
44.00	36.36	54.00	11.11	64.00	6.25	74.00	18.92
.20	35.75	.20	10.70	.20	6.54	.20	19.14
.40	35.14	.40	10.29	.40	6.83	.40	19.35
.60	34.53	.60	9.89	.60	7.12	.60	19.57
.80	33.93	.80	9.49	.80	7.40	.80	19.79
45.00	33.33	55.00	9.09	65.00	7.69	75.00	20.00
.20	32.74	.20	8.69	.20	7.97	.20	20.21
.40	32.16	.40	8.30	.40	8.25	.40	20.42
.60	31.58	.60	7.91	.60	8.53	.60	20.63
.80	31.00	.80	7.53	.80	8.81	.80	20.84
46.00	30.43	56.00	7.14	66.00	9.09	76.00	21.05
.20	29.87	.20	6.76	.20	9.36	.20	21.26
.40	29.31	.40	6.38	.40	9.63	.40	21.47
.60	28.76	.60	6.01	.60	9.90	.60	21.68
.80	28.21	.80	5.63	.80	10.17	.80	21.88
47.00	27.66	57.00	5.26	67.00	10.44	77.00	22.08
.20	27.12	.20	4.89	.20	10.71	.20	22.28
.40	26.58	.40	4.53	.40	10.97	.40	22.38
.60	26.05	.60	4.17	.60	11.24	.60	22.68
.80	25.52	.80	3.81	.80	11.50	.80	22.88
48.00	25.00	58.00	3.45	68.00	11.76	78.00	23.08
.20	24.40	.20	3.09	.20	12.02	.20	23.28
.40	23.96	.40	2.74	.40	12.28	.40	23.47
.60	23.45	.60	2.39	.60	12.53	.60	23.66
.80	23.15	.80	2.04	.80	12.79	.80	23.86
49.00	22.45	59.00	1.69	69.00	13.04	79.00	24.05
.20	21.95	.20	1.35	.20	13.29	.20	24.24
.40	21.46	.40	1.01	.40	13.54	.40	24.43
.60	20.97	.60	0.67	.60	13.79	.60	24.63
.80	20.48	.80	0.33	.80	14.04	.80	24.82
50.00	20.00	60.00	0.00	70.00	14.28	80.00	25.00

The per cent of full load on which tests should be made will vary with the class of work on which the meter is used. Where the load connected to the meter is such that it will be used uniformly over the range of

the meter tests should be made at 10 per cent, 20 per cent, 30 per cent, etc., (10 per cent intervals) over the full range of the meter. On the other hand, if the load is such that only the full load connected to the meter is used, such as on an electric sign, more tests should be made at the full load capacity. On the ordinary residence load a test at 4 per cent and 100 per cent of full load will generally suffice.

Meters carrying large loads should be tested every 30 days. If the meter is placed where there is much jarring it will tend to run fast.

All meters have a tendency to gain in speed because of the gradual weakening of the controlling magnets.

Commutator troubles are the greatest source of inaccuracies of meters. Some operators insert small fuses in armature circuit. This is especially useful when there is danger from lightning.

READING OF METERS

As has been previously stated, the basis of all recording wattmeter readings is the kilo-watt hour, the equivalent of one kilowatt used for one hour. It is not necessary that exactly a kilowatt of current be used, or that the current be used for the exact period of one hour, but that the product of the watts and the hours shall equal 1000 watt-hours. For instance: A 16 candlepower lamp taking 50 watts and burning for 20 hours represents one kilo-watt hour. Twenty of these 50 watt lamps burning for a period of one hour also represent one kilo-watt hour.

Meter readings are indicated by the positions of pointers which move over a number of dials as shown

in Figure 198, the difference between any two readings representing the amount of power used during the interval between these readings. The pointers shown on the dials in Figure 198 are so connected by means of clockwork that a total revolution of any pointer represents 1/10th of a revolution of the pointer to the left of it. It will also be noted that each dial reads in opposite directions to the one next to it.

At the top of the individual dials the value of the reading of that dial is shown. Where the figures given are followed by the letter "s" it signifies that each division of the dial represents the amount of current indicated by the figure at the top. For instance, in Figure 200 each division of the dial at the right represents 1/10th of one kilowatt and a total revolution of the dial 10/10ths or 1 kilowatt. In a like manner, each division of the second dial from the right represents 1 kilowatt and a total revolution of the pointer on this dial, 10 kilowatts.

If the figure given at the top of the dial is not followed by the letter "s", or as shown in Figure 199, each division of the dial represents 1/10th of the amount shown at the top of the dial, the dial at the right of Figure 199 indicating 9/10ths of 10 kilowatts or 9 kilowatts.

The reading of a meter should always be from right (lowest dial) to left, each reading of the dial at the left being used as a check on the reading of the dial at the left. The following examples will make clear the manner of reading meters:

In Figure 198 the right hand pointer registers 9/10ths of 1000 watt hours or 900 watt hours; the

pointer next to it registers 8 (it cannot have passed the figure 9 as the pointer on the dial at the left of it has not made a complete revolution); the middle dial

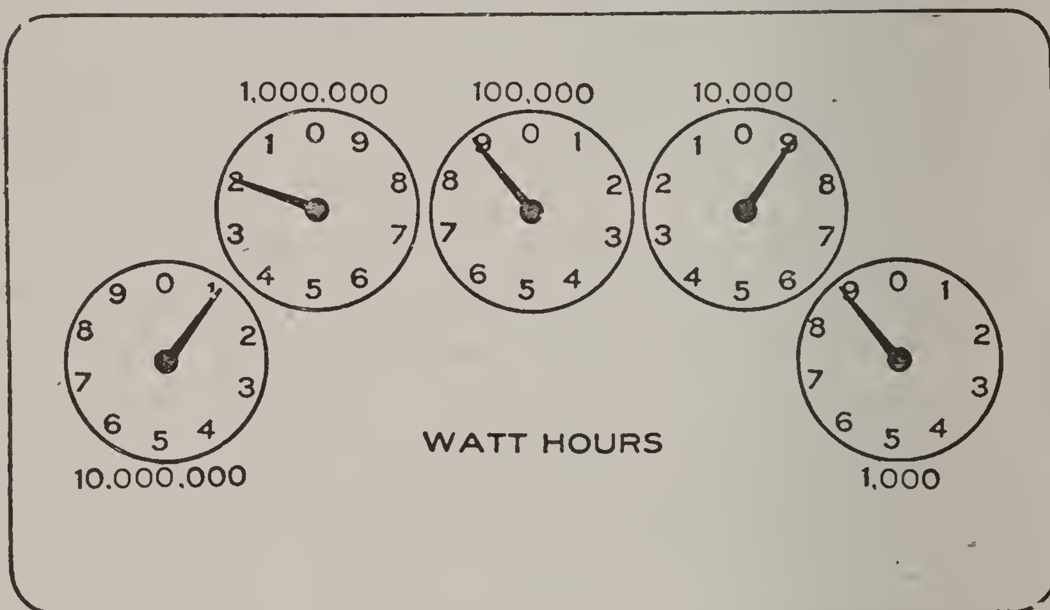


Figure 198

also registers 8; as the middle pointer has not passed the 0, the 4th dial must be read 1; the last dial also

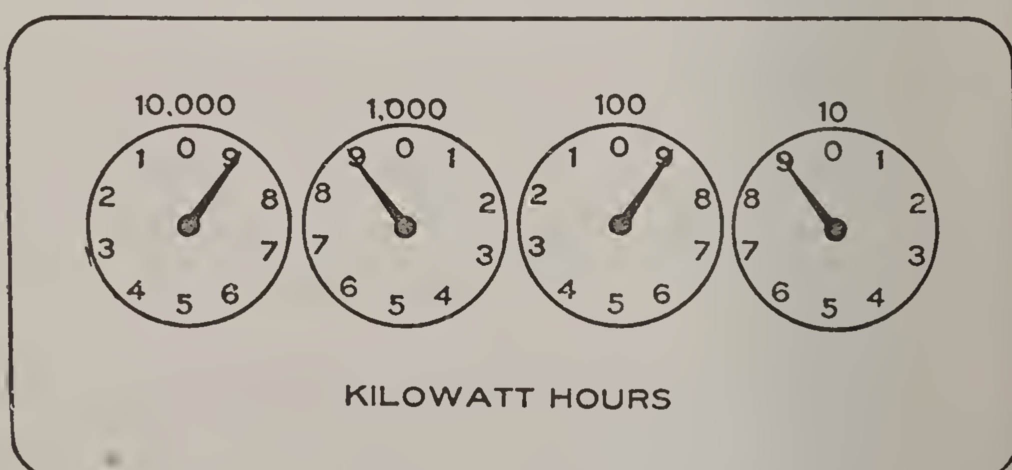


Figure 199

indicates 1, making the total reading 1,188,900 watt hours.

In Figure 199 the readings on the meter dial are

shown in kilowatt hours. The first pointer at the right reads 9; as this pointer has not passed the 0 mark, the dial to the left must be read 8; each of the remaining

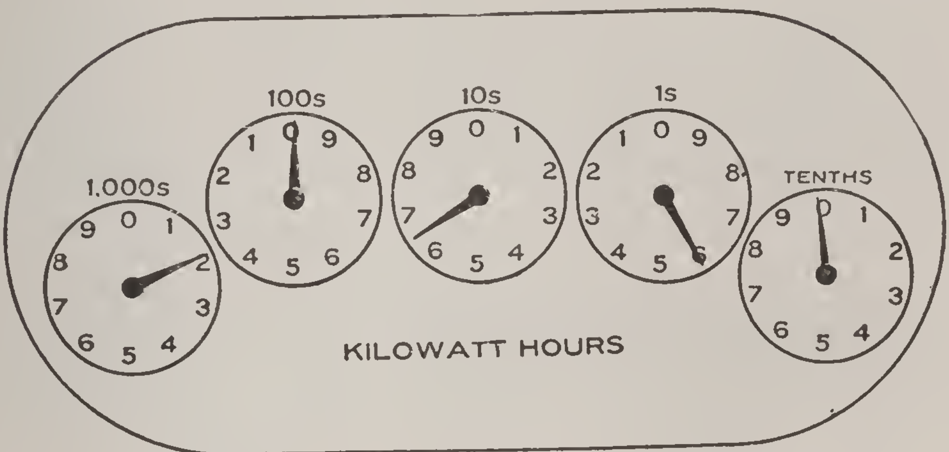


Figure 200

dials also reads 8, the total reading being 8889 kilowatt hours.

In Figure 200 the readings are also given in kilowatt hours. The pointer on the first dial at the right

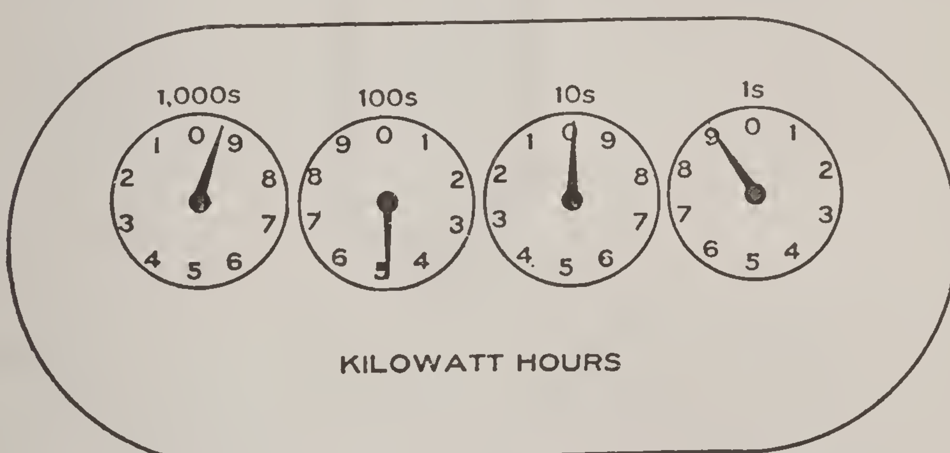


Figure 201

has not passed the 0 mark so this dial must be read 9/10ths of a kilowatt hour or .9; the second dial reads 5; the middle dial 6; the fourth dial 9 and the last dial 1, making the total reading 1965.9 kilowatt hours.

In Figure 201 the dial at the right indicates 9 kilo-

watt hours; the second dial 9; the third 4, and the fourth 9, making a total reading of 9499 kilowatt hours.

On some types of meters a multiplier is used. This is generally given on the meter dial and the readings as indicated by the pointers should be multiplied by this number to obtain the correct reading of the meter.

DISCOUNT METER

Figure 202 shows a diagram of what is known as the Wright discount or demand meter. This meter is

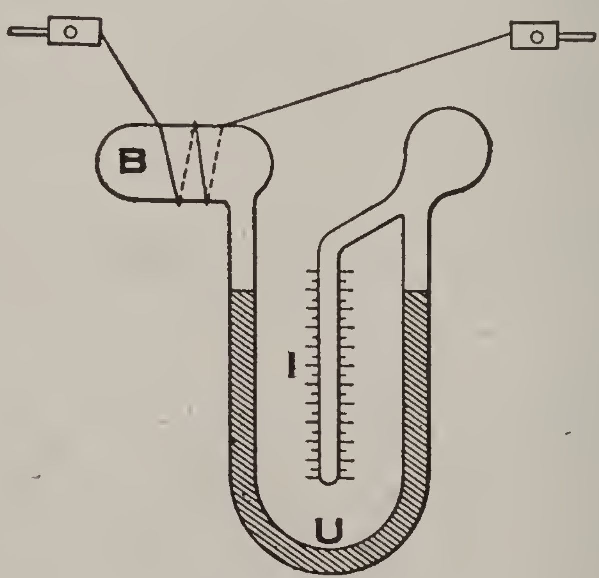
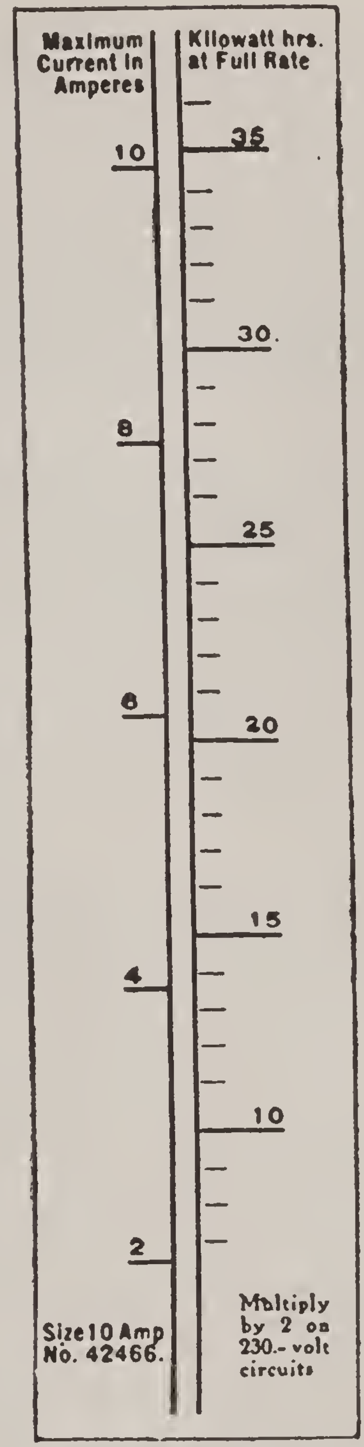


Figure 202

used on circuits where it is desired to know the maximum current which has passed through the circuit. In the diagram, B is a glass bulb connected to a tube U which is partly filled with a liquid. Around bulb B is wound a resistance wire which carries the main current. When current flows in this wire heat is generated and the air in the bulb is expanded, thus forcing the liquid around tube U until it reaches the point where tube U and I join, when it will flow into



SCALE OF DISCOUNT METER

Figure 203

tube I. The amount of liquid in tube I will depend upon the maximum current which has passed through the resistance wire on bulb B. The meter is not af-

fected by momentary increases in current. If the maximum current lasts five minutes, 80 per cent will register; ten minutes, 95 per cent will register; thirty minutes, 100 per cent will register. Figure 203 shows the scale of this meter. The left-hand scale shows the maximum current used in amperes and the right-hand scale the kilowatt hours for which the customer must pay full rate.

As a discount meter, this meter is connected in series with one of the mains connecting to the ordinary recording wattmeter. On three-wire circuits a discount meter must be connected in each main, this requiring two meters. As the scale is computed for 115 volt circuits, when the meter is used on a 230 volt circuit the reading must be doubled, as indicated at the bottom of the scale.

The recording wattmeter registers the total consumption of energy and the discount meter the proportion of it to be charged at full rate. The excess of the recording wattmeter reading over the discount meter reading is subject to the lower rates as specified by the lighting company. In case the wattmeter reading is less than the discount meter reading only the consumption as shown by the recording wattmeter is charged at the full rate.

The discount meter shows the full rate portion of the bill for one month of 30 days. When computing a bill for a greater or less time the reading should be proportioned according to the time. After each monthly reading the meter is opened and the tube tipped up until all the liquid flows out. If there is current in the meter, the liquid will flow back again

when the tube is turned down; otherwise the tube will remain empty until current is used.

The purpose for which this discount meter is used is to obtain a more equitable basis for the charge for current. As practically all users of current, for lighting for instance, use the maximum amount of current at the same time, the cost to the lighting companies of both the generation of this current and transmission of it to the consumer is a maximum at this time. They must have sufficient generating apparatus and transmission lines to supply the demand and the line losses at this time are considerably greater. This extra equipment must be maintained for the short interval during which this extra demand is made, or at the peak of the load.

It is assumed that a consumer will use the maximum amount of current for one hour each day during the thirty days of the month, and the kilowatt hours to be paid for at full rate are computed on this basis. Suppose a current of ten amperes was indicated by the maximum meter as the greatest amount of current used during the month. Ten amperes at 115 volts amounts to 1150 watts, and this amount used for one hour a day for 30 days represents $30 \times 1150 = 34{,}500$ watt-hours or 34.5 kilowatt-hours as the amount of current to be paid for at the full rate. An examination of the meter scale as shown in Figure 22 will show that a current of ten amperes is equivalent to 34.5 kilowatt-hours at the full rate.

CHAPTER XXII

LIFE AND FIRE HAZARD

Electricity may endanger life or seriously maim in two ways: By direct contact, causing severe shock and often instant death, and by burning through the medium of a flash or arc which may also prove destructive to the eyesight.

A shock may be obtained by touching wires of opposite polarity; by touching one wire and making connection to the ground, the other wire being grounded, or by cutting one's self into the circuit.

It is perfectly safe to touch any one bare wire provided one is perfectly insulated from the ground, and even if one is not insulated, if the wires are clear from the ground no harm will be done, but under no circumstances should one ever trust a system of wiring, a ground may come on at any moment and cause instant death. The general rule for handling live wires of high potential is, to use only one hand at a time and keep well insulated from the ground and from wires of opposite polarity.

While working on dead lines that are connected with stations over which the workman has no control and which may be connected up by mistake at any moment, it is a good plan to short circuit those wires and ground them. If now the station attendant should

throw in switches no harm would be done except to his fuses

Whenever it is necessary to cut wires carrying current, they should be merely cut into a little with the pliers (to cut clear through will burn the pliers) and then the wire may be broken, but under no circumstances should one bridge the cut with arms or hands. The breaking of the circuit will produce an enormous voltage for an instant which may be amply sufficient to cause death to any one holding the ends of a broken wire. If a high potential circuit is to be broken in this way it is best to work the wire in two with a stick.

The severity of a shock obtained from a circuit will depend upon the voltage of the circuit, the degree of contact the person makes with the wires, the condition of the body where it touches, whether moist or dry, and the quality of the ground which may be helping to make the circuit through the body. Thus it is by no means always safe to touch a live wire of 200 volts nor always fatal to receive a shock from 2000 volts.

Many people have been killed by the lower voltage and many have escaped unharmed from shocks obtained from the higher pressure.

The greatest danger to the eyesight and from burns is encountered while fusing up or throwing in switches on circuits carrying heavy currents. Many switches are built so that the handle is directly above the fuses. In case such a switch is thrown in while there is a short circuit on the line the operator's hands are likely to be burned very badly. It is best to cover the fuses with asbestos or to procure a stick with which the switch may be pushed in.

Where circuits are controlled by circuit breakers there should always be a switch which must be open until the breaker is set so that the hand may not interfere if the breaker should start to go out at once because of overload or short circuit.

To install fuses in a live circuit which cannot be disconnected by switches is always a matter attended with some risk. As a rule the nature of the "blow"

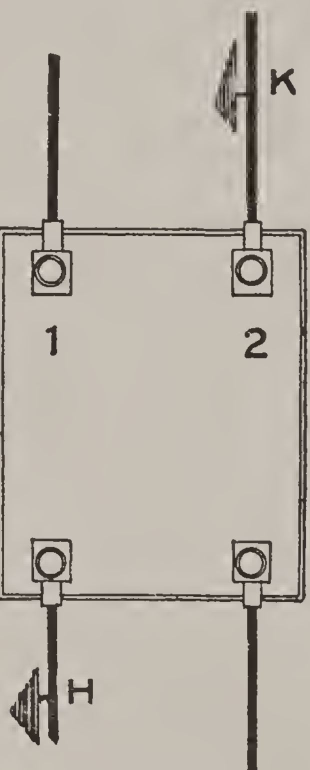


Figure 204

will give some idea as to whether it was caused by an overload or a short circuit. The current due to a short circuit will generally be many times greater than that of an overload owing to the fact that it requires some time for the fuse to heat. If there is indication that there is a short circuit, tests had better be made before attempting to install the proper fuses. A circuit supplying a large number of lights cannot be tested for

"short" in the ordinary manner because the lights establish a circuit of low resistance. If both fuses are out, the best way to test it is, by connecting a small fuse into the circuit, trying one side of the fuse block at a time. If there should happen to be two grounds, as at H and K, Figure 204, a fuse installed at 1 will not blow, but placed in 2 it will. If each side singly holds a small fuse without blowing, a fuse of the proper size may be safely installed on one side. When this is done a piece of wire of suitable size may be fastened to one of the terminals on the opposite side and this wire used to bridge the other fuse gap The wire should be of such a length that the workman need not endanger his eyes or hands while making connection. If the fuses in question are very large the first fuse may be covered with asbestos. If the first fuse does not blow when the circuit is completed with the wire (known as a "jumper") the second may be installed, leaving the wire to carry the current until the fuse is in place.

The fire hazard of electric wiring consists in the possibility of overheating wires when carrying too much current; where circuits are broken an arc is always established which may communicate fire; where wires come in contact with wood moisture may cause a ground along which current may flow, eventually charring the wood and starting a fire; wires may come in contact with gas pipes and gradually, by making intermittent contact, eat holes into the pipe, allowing gas to escape which finally is fired by the spark.

Lamps and motors may also become so much over-

heated as to communicate fire to combustible material. Many fires are also caused by small sparks as from switches and sockets setting fire to gases or lint in factories.

An incandescent lamp ordinarily does not become very hot but when covered over with paper or cloth or when subject to an abnormal voltage it may easily cause fires. Many of them have done so.

CHAPTER XXIII

GROUND DETECTORS AND LIGHTNING ARRESTERS

As a rule all systems of wiring should be kept free from grounds. The exceptions to this rule are three-wire systems of such magnitude that it becomes practically impossible to do so, and in such cases the neutral wire is permanently grounded.

In some cases it may be advisable to install ground detectors that give continuous indications, but as such indicators introduce a permanent ground which under favorable circumstances becomes an aid in breaking down the insulation of the opposite polarity from the one to which it is attached, this is not generally desirable.

Either of the lamp systems of ground detectors here described can be made continusuoly indicating by permanently closing the switch which connects the lamps to ground and voltmeters may be used in place of the lamps.

Figure 205 is the simplest and cheapest of all ground detectors. Only two lamps and a push button are required. As long as the lamps are not connected to the ground, they burn in series at about half candlepower. If the switch is kept closed and a ground occurs on one side of the system, the lamp on that side

burns dull and the other becomes brighter. If the ground is very "good," the lamp on the side of the ground will be entirely extinguished and the other will be at full candlepower.

Figure 206 shows method of using voltmeter as

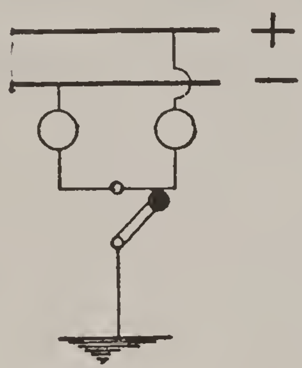


Figure 205

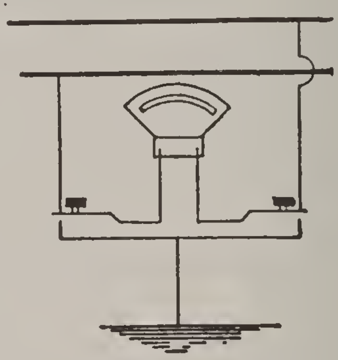


Figure 206

ground detector. The lamps shown above are not very sensitive and will not indicate a slight ground. Hence the voltmeter is preferable. As long as both buttons are in their normal position, the voltmeter measures the voltage of the system. By pressing down either

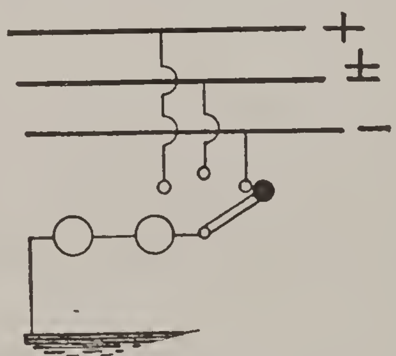


Figure 207

button, if a deflection is obtained, it indicates a ground on that side of the system to which the button belongs.

Figure 207 shows ground detector connections using lamps for an ordinary three-wire or three-phase system. Used in connection with the ordinary three-wire

system, no indication will be obtained while the switch is connected to the leg that is grounded. If one leg is grounded the lamps will be either at full or half candlepower, depending upon which leg the switch is placed.

With three-phase systems, also, no indication will be obtained as long as the switch is connected to the grounded leg. When it is connected to the other legs the lamps will burn bright.

Another ground detector for three-phase systems is shown in Figure 208.

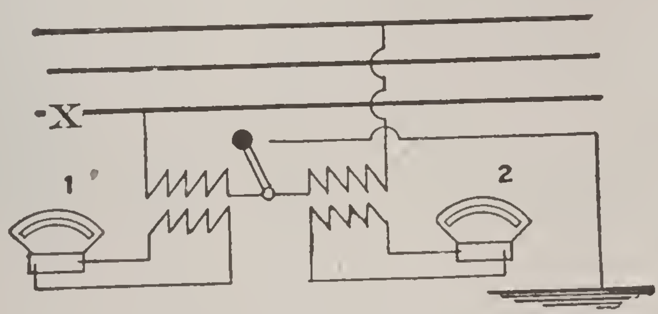


Figure 208

With this connection as long as the line is clear the two voltmeters show even pressure. With a ground coming on one side, say at X, voltmeter 1 will read lower and 2 higher; with a ground on the opposite side 2 will read low and 1 high. With a ground on the middle wire, both will read higher.

Ground detectors like the above are reliable only if one side of the system is clear. The ground on any side acts as a shunt to the lamp on that side and if such shunts exist on both sides, it is clear that the indications will be confusing. Tests should, therefore, be frequently made so as to be reasonably sure that a ground will be detected as soon as it comes on.

If a system is to have a thorough test, it must be disconnected and tested with a Wheatstone bridge or other method described elsewhere.

LIGHTNING ARRESTERS

A lightning discharge takes place only in obedience to an enormous pressure and is of very short duration. During this exceedingly short time the counter E.M.F. of magnets and other inductive arrangements is so

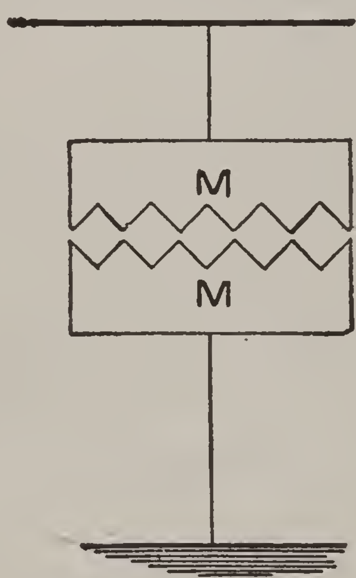


Figure 209

great that it is easier for the current to jump a small air gap than force its way over an ordinary transmission line.

The simplest form of lightning arrester is shown in Figure 209. When the discharge occurs, the current jumps the spark gap between the two metal plates M. If these are connected to a dynamo circuit carrying much current, the arc established by the lightning discharge will be maintained by the dynamo and the result will be a short circuit. This type of arrester can,

therefore, be used only in connection with circuits such as telegraph or telephone in which the currents are not of sufficient strength to maintain an arc.

A single plate of this kind is also useful if mounted closely to belts which give trouble from static charges.

The best known type of lightning arrester is that of Prof. Thomson. In this, the arc which is established by the discharge, is immediately blown out magnetically by the dynamo current. Entering at L, Figure

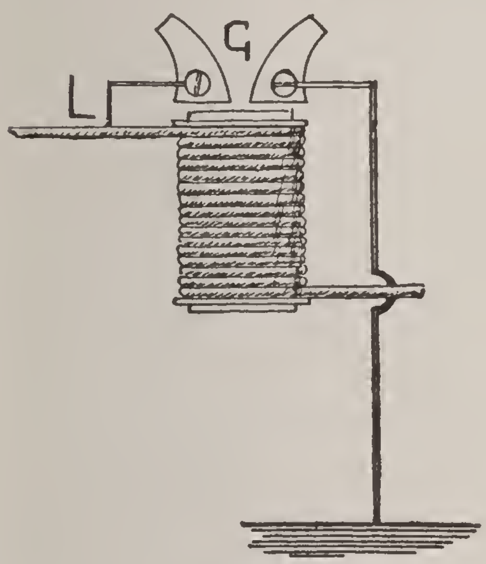


Figure 210

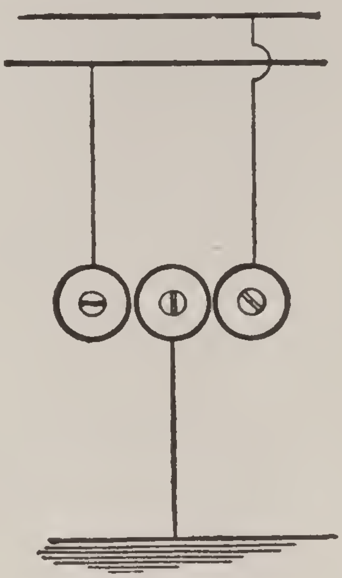


Figure 211

210, the lightning jumps the gap G and passes to ground. The magnetism existing in the coil forces the arc upward until it breaks It is essential that this arrester be so connected that the side L is toward the outside lines.

Another form of lightning arrester is illustrated in Figure 211. This form is used with alternating current circuits only. It consists of three cylinders placed very close together as shown. These cylinders may be of non-arcing metal, and besides offer such a large sur-

face over which the arc spreads that it does not create a high enough temperature to maintain itself. Ordinarily only a very small spark is noticed.

For use with high voltages either of the foregoing forms may be connected in series. Each wire leading overhead to the outside should be protected. The ground wire for lightning arresters should be as straight as possible; should be of copper, never of iron and should not be run in proximity to iron.

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